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The role of seasonal salt and water fluxes in the genesis of solonetzic B horizons.

University — Université

University of Alberta

Degree for which thesis was presented — Grade pour lequel cette thèse fut présentée

M.Sc. in Soil Science

Year this degree conferred — Année d'obtention de ce grade Spring 1981	Name of Supervisor — Nom du directeur de thèse Dr. S. Pawluk

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THE ROLE OF SEASONAL SALT AND WATER FLUXES IN THE GENESIS OF SOLONETZIC B HORIZONS

by

© SANDRA LEE COATES LANDSBURG

A THESIS
SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH
IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE
OF MASTER OF SCIENCE

DEPARTMENT OF SOIL SCIENCE

EDMONTON, ALBERTA
SPRING, 1981

THE UNIVERSITY OF ALBERTA

RELEASE FORM

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TITLE OF THESIS:	The Role of Seasonal Salt and Water Fluxes in the Genesis of Solonetzic B Horizons
DEGREE FOR WHICH THESIS WAS PRESENTED:	Master of Science in Soil Science
YEAR THIS DEGREE GRANTED:	Spring, 1981

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S. Pawluk

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Date Feb. 17, 1981

FOR DANNY

WITH LOVE

ABSTRACT

The purpose of this study is to further the knowledge on the genesis of Solonetzic soils in the Province of Alberta. This research deals specifically with an evaluation of the salt and water fluxes into Solonetz soils at two sites in East-Central Alberta. Both sites have soils classified in the Solonetzic Order of soils, and the soil pedons investigated in this study are those from the Black Solonetz Subgroup.

In order to identify the processes likely responsible for the development of the B horizon of Solonetzic soils, the following field and laboratory investigations were undertaken. Field work involved: weekly sampling in 10 cm increments from the soil surface down to a depth of 80 cm; collecting groundwater samples from water table wells and piezometers; measuring the depth to groundwater in water table wells and piezometers; measuring soil solution conductivity using salt cells; collecting horizon samples from each profile; taking depth-moisture readings using a neutron probe; and taking soil-temperature readings from 0 to 183 cm. This field work was done throughout the entire year in order to determine seasonal variabilities. Dyes were also added to the soil surface and deepest piezometers in order to measure both upward and downward movement of water through the soil.

Laboratory investigations involved measuring the soluble salts, pH, EC, and %mc in the weekly soil samples as well as in the groundwater samples. The soil profiles at each of the two sites were characterized by conducting the following physical and chemical analyses on each of the horizons; soluble salts; cation exchange capacity and exchangeable cations; pH; exchange acidity; percent organic matter; total nitrogen; calcium carbonate percentage; field capacity and wilting point; and particle size analysis.

Conclusions from this study show that the predominant mode of moisture movement into the soil pedon is by capillarity. This type of movement occurs along with both lateral and downward movement of water: lateral movement on top of the B horizon when it is wet and downward movement through this horizon when it is dry. Solonization occurs on top of the B horizon and the salts responsible are sodium bicarbonate and sodium sulfate. These salts are brought upwards into the soil pedon by capillary movement and are concentrated by evaporation during the warm months and crystallization during the cold months. Leaching by precipitation and snow melt removes excess salts. The alternation of these two processes results in the sodium ion becoming adsorbed onto the soil colloids in amounts leading to solonization and the physical and chemical characteristics associated with Solonetz soils. Salts and moisture are related within the soil pedon as both are most variable near the soil surface, increase down the pedon, are fairly consistent over time and follow the same general annual trends. The genesis of Solonetzic soils occurs throughout the entire year. Salts accumulate during the winter and summer months by capillarity and concentrate by evaporation and crystallization. Excess salts are leached by precipitation and snow melt in the spring, summer and early fall months thus creating conditions possible for solonization.

This thesis has developed some new ideas as to the genesis of Solonetz soils as well as supported some old ones. More research is needed in this area in order to develop techniques for the reclamation of these soils.

ACKNOWLEDGEMENTS

Many thanks are extended to Dr. S. Pawluk for his guidance and encouragement throughout this investigation. Appreciation is also extended to Dr. S. Chanasyk of the Department of Soil Science and Prof. E. Rapp of the Department of Agricultural Engineering for advice on groundwater aspects and serving on the thesis committee.

Special thanks are given to Dr. M. Dudas and Mr. P. Yee of the Department of Soil Science for demonstrating that chemistry can be understood and even enjoyed.

Appreciation is expressed to Mr. Beamer and Mr. Paulencu for allowing the use of their land.

Thanks are extended to Mr. W. Szabon of Alberta Environment for allowing extra time to work on this thesis, without which this thesis would have been a long time in coming.

Many thanks are expressed to the Alberta Department of Agriculture for drilling the holes for the piezometers and water wells at the Beamer and Paulencu sites.

Appreciation is extended to the University of Alberta and National Research Council for scholarships awarded during the study period.

The author extends a very special thank-you to Dan Dagenais for all his encouragement and love as well as his forbearance throughout this study.

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INTRODUCTION

There are approximately 4.3 million hectares of Solonetzic soils in the Province of Alberta. These soils may exist alone in large areas or may be intermixed with some of Alberta's most fertile soils, those of the Chernozemic Order. Solonetzic soils, because of limitations in their chemical and physical properties, create an environment that is not conducive to good plant growth and as a result, crop productivity on cultivated land is low.

Researchers have been studying Solonetzic soils since 1889. V. Vernadskiey was the first to establish that soil properties were changed by salt solutions and saline soils could become solonetzic (Tyurin *et al*. 1967). He also questioned whether there was an evolutionary relationship between sodic and saline soils. Since that time much effort has been spent researching Solonetzic soils. The problem that exists is not that information is lacking but that little information has been collected on these soils in the Canadian environment. Studies that have been carried out in Canada usually cite the genesis of Solonetzic soils in terms of research done many years ago in Europe.

Since land is now a very limited resource the reclamation of Solonetzic soils is becoming increasingly important. Before suitable reclamation practices can be established, additional knowledge as to their mode of genesis in the Canadian environment is essential.

It is the purpose of this study to further the knowledge on the genesis of Solonetzic soils in the Province of Alberta. This study deals specifically with an evaluation of the salt and water fluxes into Solonetz soils at two sites in East-Central Alberta. The first site is situated fifty-six km east, and the second site eighty km east, of the City of Edmonton. Both sites have soils classified in the Solonetzic Order of soils, and the soil pedons investigated in this study are those from the Black Solonetz Subgroup. Solonetzic soils at site one have developed from lacustrine parent material while the pedons at site two have developed from weathered residual Edmonton formation.

In summary, this research proposes to identify the processes likely responsible for the development of the B horizon of Solonetzic soils. This will be accomplished by concentrating on the roles played by seasonal variations in salt and water fluxes. Specifically, an attempt will be made to answer the following four questions:

1. To determine the movement of moisture within the soil profile. Is moisture moving dominantly upwards into the soil profile in the form of groundwater, downwards into the profile by infiltration, laterally within the profile as throughflow, or by a combination of the three processes?
2. To determine the amounts, types, and movement of salts within the soil profile. What amounts and/or types of salts are responsible for the formation of the Solonetzic B horizon and how do they move within the soil profile?
3. To determine the relationship between the salts present and the moisture profile. Are the movements of these factors related and how do they aid in the formation of the B horizon?
4. To determine the role of season in the genesis of Solonetzic soils. Do the majority of the soil forming processes occur in the spring/summer months or in the fall/winter months?

In order to determine the foregoing the following field and laboratory investigations were undertaken. Field work involved: weekly sampling in 10 cm increments from the soil surface down to a depth of 81 cm; taking groundwater samples from water table wells and piezometers;

measuring the depth to groundwater in water table wells and piezometers; measuring soil solution conductivity using salt cells; taking horizon samples from each profile; taking soil temperature readings; and taking depth-moisture readings using a neutron probe. This field work was done throughout the entire year in order to study the effect due to season. Dyes were also added to the soil surface and deepest piezometers in order to measure both upward and downward movement of water through the soil.

Laboratory investigations involved measuring the soluble salts, pH, electrical conductivity, and percent moisture content in the weekly soil samples as well as in the groundwater samples. The soil profiles at each of the two sites were characterized by doing the following physical and chemical analyses on each of the horizons; soluble salts; cation exchange capacity and exchangeable cations; pH; exchange acidity; percent organic matter; total nitrogen; calcium carbonate percent; field capacity; wilting point; and particle size analysis.

REVIEW OF THE RELATED LITERATURE

The review of the related literature deals with specific aspects concerning the development of Solonetz soils which are studied in this thesis. The major theories as to the genesis of these soils are investigated. The roles played by groundwater, salts, and season are considered as well.

I. THEORIES OF GENESIS OF SOLONETZIC SOILS

The first scientifically supported theory on the origin of sodic soils was presented by E.W. Hilgard who felt that in the majority of cases their existence was definitely traceable to climatic conditions alone. Hilgard (1907) stated that, "these soils are the natural result of a light rainfall insufficient to leach out of the land the salts that always form in it by progressive weathering of rock powder of which all soils largely consist. Where the rainfall is abundant, that portion of the salts corresponding to "sea salts" is leached out into the bottom water and with this passes through springs and rivulets into the drainage to be finally carried to the ocean. Another portion of the salts formed by weathering, however, is partially or wholly retained by the soil; it is that portion chiefly useful as plant food." Hilgard noted that in arid climates, the salts remained in the soil. Being largely soluble in water, evaporation during the dry season brought them to the surface where they would accumulate. He found sodium sulfate, sodium chloride, and sodium carbonate to be the major salts in these soils.

Hilgard also introduced the terms "white alkali" and "black alkali". The former refers to soil profiles where the neutral salts of chlorides, sulfates, and nitrates predominate, and the latter to soil profiles that are dominated by chemically alkaline soil salts such as soluble carbonates.

After numerous experiments with artificial salinization of a Chernozem by adding sodium chloride and sodium sulfate followed by washing the chloride and sulfate out of the soil with water, K. Gedroyts in 1912 reached the conclusion that a Solonetz consisted of a soil in which the inorganic and organic compounds were enriched with the cation sodium. He stated that the source of sodium was a soil solution rich in sodium salts. Therefore, Gedroyts reasoned that Solonetz soils were closely related by origin to Solonchaks; indeed that Solonetz were formed from Solonchaks regardless of the nature of the source of the salts that took part in its formation (Ivanova and Bol'shakov 1972). Gedroyts believed that sodium salts reacted with the soil by a base exchange (cation exchange) reaction. In this way, sodium became adsorbed and an equivalent amount of other bases (chiefly calcium) were set free. The latter bases and any remaining sodium salt were leached out: thus, the sodium originally combined as a soluble salt, came to comprise a high percentage of the exchangeable bases of the soil. When sodium salts comprised most of the soil salts, the natural leaching caused dispersion which resulted in fine grained particles being washing down in the subsoil, thus developing dense sub-horizons. Gedroyts used the term Solonetz as denoting a soil which contained relatively large amounts of exchangeable sodium (Kelley 1951).

Gedroyts developed the terms salinization, desalinization, solonetzization and solodization to describe the steps in the genesis of Solonetzic soils. He described salinization as an accumulation of soluble salts which brought about the formation of a Solonchak. A soil whose adsorption complex contained adsorbed sodium and was adequately salinized by sodium chloride or sodium sulfate was called a pure Solonchak (Ivanova and Bol'shakov (1972). This salinization Gedroyts believed, could result by frequent periodic salinizations or simply by one appearance of these salts. Under prolonged leaching, the salts were removed and desalinization occurred. Gedroyts felt that some desalinization was necessary for the next process, solonetzization, to begin. Solonetzization involved the dispersive action of sodium and the formation of the specific morphological features associated with these soils. A soil with adsorbed sodium but no sodium chloride or sodium sulfate was called a pure Solonetz. Solodization was the process of degradation and resulted in a soil called a Solod. Solodization was a very vigorous process and Gedroyts felt that it began as soon as a Solonchak changed into a Solonetz (Kelley 1951).

Rode (1962) agreed with Gedroyts in that he found Solonetz soils to occur frequently in nature when a saline soil was subjected to leaching of the salts out of the soil stratum. He also called this desalinization. Rode found desalinization to be due to the increasing humidity of the climate or more often, to the lowering of the water table (Rode 1962).

K.D. Glinka in 1926 related Solonetz formation to present day salinization processes (Tyurin _et al_. 1967). He believed that whenever the water table was so shallow that the rise of groundwater prevailed over the flushing of the soil by surface waters, no Solonetz developed. He found that Solonetz development required the rise of salt solutions to the surface. Glinka stated that this was not the sole prerequisite for formation and that other conditions were also required. These conditions were:

1. In climatic regions where evaporation was sufficient to cause soluble sodium salts to rise occasionally from the ground into the upper soil horizons, but where atmospheric moisture was abundant enough to prevent these salts from remaining long in these horizons, a Solonetz process gradually developed.

2. In climatic regions where soil flushing prevailed over the rise of soil moisture to the point of preventing salt from entering the upper soil horizons, no Solonetz process was possible.
3. Solonetzic soils would not form where water was too scarce for flushing of the soil profile and no accumulation of salts could occur (Tyurin _et al._ 1967).

Therefore, Glinka felt that Solonetz formation required the rise of sodium salts towards the surface followed by a downwards flushing of the soil by rainwater. Glinka stated that the constant alteration of these two processes resulted in the formation of Solonetzic soils.

The evolution of salt affected soils, according to de Sigmond (1926) "begins when a territory of arid or semi-arid climate becomes periodically exposed to an excess of water and the subsoil prevents the salts dissolved in the water from filtering through. Later the salt solution becomes more and more concentrated because of evaporation and in turn the chemical and physical composition of the soil undergoes transformation in the above mentioned manner". de Sigmond discovered that although conditions varied from place to place, it was possible to name periods or steps in the evolution of this soil type. These periods were:

1. The formation of an impermeable subsoil layer which hindered the filtration and drainage of water and salt solutions which accumulated on the soil surface.
2. Surface evaporation of water and concentration of soil solution combined with an intensive mineral and organic decomposition.
3. An exchange of bases produced by the sodium salts reacting with the soil zeolites and humates which resulted in different salt affected soil types, according to the quantity and quality of the different sodium salts and the original composition of the soil material (de Sigmond 1926).

de Sigmond found these periods or steps of evolution to be repeated many times and resulted in a great variety of salt affected soil formations. The original composition of the soil and water which accumulated on and in the soil was of primary importance, and whenever conditions such as those mentioned above existed, salt affected soils would eventually form.

A cycle of evolution was developed by Kellogg (1936) for the alkali soils in western North Dakota. The cycle illustrated in Figure 1 is similar in concept to the theories that have already been discussed. Kellogg believed that a normal soil, through various processes, could develop into a Solonchak, then further to a Solonetz and Soloth. A normal soil had to be salinized in order to become a Solonchak. Improved drainage resulted in the formation of a Solonetz soil, and Soloths formed as a consequence of the process of solodization. Therefore, a normal soil could become salinized, desalinized, and eventually once again evolve to a normal soil.

Vil'yams proposed a theory based on a single soil-forming process for the development of a Solonetz. Accordingly the change over from a meadow to a steppe type of vegetation was believed to result in two consequences:

1. The gradual decrease in humus and organic matter in the soil due to the decreased annual amount added.
2. In drought seasons there was a constant accumulation of mineral salts, especially soda within the "leafy" or "soddy" horizons (Tyurin et al. 1967).

Salts formed in the summer were illuviated by autumn rains down to a lower horizon in the soil where they accumulated and formed a salt bearing horizon. The spring rise of moisture was insufficient to remove

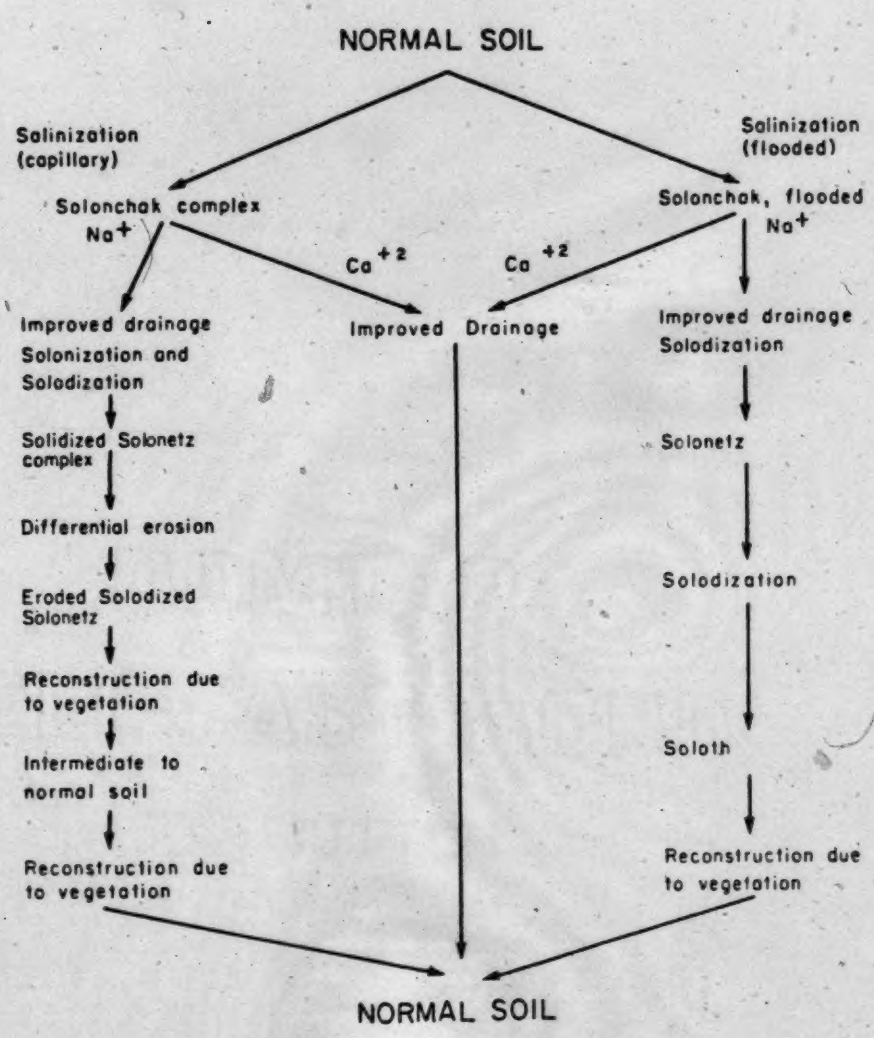


Figure 1: The cycle of evolution of alkali soils from Western North Dakota (After Kellogg 1936).

the lime and gypsum, therefore these accumulated in the horizons and formed a calcareous or gypsyferous horizon in the soil. Whatever solution reached the soil surface merely contained salts of monovalent metals, which displaced the calcium adsorbed in the humus and replaced it by sodium. The humus, in which the absorbed base was sodium, formed a colloidal suspension in water and became unstable. The aggregates cemented by the organic matter became dissolved in water, giving rise to a structureless material viscous when moist and hard when dry and fractured by vertical cracks into columnar jointings (Tyurin et al. 1967). Therefore, Vil'yams proposed a vertical distribution of salts in the soil profile.

Szabolcs (1971) found that the presence of sodium salts in a certain concentration in the soils liquid phase did not necessarily result in the evolution of a Solonetz soil. An essential condition that was also necessary was that the salt solutions must have migrated alternately upwards and downwards in the soil profile (Szabolcs 1971). As a result, the soil involved became alternately drier or more humid inducing numerous essential reversible and irreversible changes in the soil profile. Therefore, during its upward and downward migration, the soil solution dissolved and accumulated certain products; in the case of repeated migrations the interaction between the solid and liquid phase of the soil took place under altered conditions. Thus these movements caused not only certain changes in the materials but they also resulted in the translocation of various compounds within the soil profile. Upward and downward migration of the salt solutions as well as a dilute concentration of sodium salts were required for Solonetz formation.

Arshad and Pawluk (1966) found Solonetz soils to occur in relatively flat lying groundwater discharge areas where the capillary rise from a permanent water table was sufficient to maintain a high salt level in the lower B horizons. Smith (1950) stated that the Solonetz soils of Southwestern Australia occurred in depressions and flats where surface drainage was poor and water logging occurred during the winter months while drought conditions prevailed over the long dry summer. The Soil Survey Staff of the United States Department of Agriculture (1967) believed that Solonetz soils were formed when drainage improved under natural conditions. Then "with leaching and the removal of excess salts, the Sodium-Solonchak may change to a Solonetz or a Solodized Solonetz and perhaps finally into a Solod before the processes responsible for the formation of a zonal soil become dominant".

From the foregoing, it can be seen that the study of Solonetzic soils has continued since 1907. Even though there has been 73 years of research done on the genesis of these soils, the theories that are still accepted and rarely challenged are those from the early times of Gedroyts and de Sigmond.

New opportunities are now available to reevaluate many of the older theories related to the genesis of Solonetzic soils. While it is generally accepted that the old theories are correct, the technology and instrumentation available today allows new studies to be undertaken to obtain a better understanding as to how the processes of solonization take place. The amounts and types of salt required as well as the chemical makeup and movement of groundwater through the different seasons can all be reconsidered and reevaluated on the basis of what has been previously done and reported in this section.

II. THE ROLE OF GROUNDWATER IN GENESIS OF SOLONETZIC SOILS

1. Introduction

Contained waters in bedrock aquifers in East-Central Alberta were fresh to brackish in nature at the time of deposition in a continental environment. Following the uplift and erosion of the strata above sea level, local precipitation has been slowly freshening and replacing the original formation waters in the shallower zones, mainly to depths of three hundred to four hundred feet. This may result in well waters with variable salt content, and indicates that increasing salinity could be expected locally through migration of water from adjacent beds of marine shales. In localities where saline groundwaters are shallow, it may be attributed to extremely limited movement of groundwater since post-glacial uplift and erosion (Le Breton 1963).

The sources from which groundwater supplies are obtained are: fine to medium-grained, clean or dirty, hard or soft, sandstone beds, coal seams and "quicksand" in the bedrock; sand and gravel deposits in the till, stream-trench systems, spillways; dune sand, outwash sand and gravel, and "quicksands" in the glacial drift; sand and gravel deposits within buried or partly buried preglacial river valleys; and sand and gravel deposits adjacent to rivers and lakes, permitting induced infiltration (Le Breton 1963).

Groundwater occupies the pore spaces of the materials composing the various strata. The differences between the strata as reservoirs of groundwater depend upon porosity, which is the percentage of the total volume occupied by open spaces. Porosity is controlled by the shape and arrangement, the degree of sorting, and the cementation of the rock materials. Porosity is high in well-sorted deposits and low in poorly sorted or highly cemented deposits.

The rate of movement of groundwater (the permeability) through the strata depends upon the degree of interconnection between the pore spaces and the sizes of the particles comprising the strata. Silts and clays, though highly porous, have such small pore spaces that a very large percentage of the contained water is bound to the particles by forces of molecular adhesion and such materials are frequently described as being impermeable, or of low permeability. Course gravels and sands with large openings permitting water to move freely are usually highly permeable.

2. The Movement of Groundwater

A simple flow system theoretically exists along one flank of a single symmetrical drainage basin, provided that the land surface is uniformly sloping and the porous medium is homogenous and isotropic (Tóth 1962). The basin is composed of two areas: the recharge area which is upslope from the midline and the discharge area which is downslope from the midline. Consequently the downslope half of the valley is the discharge area proper. Groundwater discharge is not concentrated in the valley bottom as long as no major stream system exists to serve as a sink line at the valley bottom and through which a large volume of surface discharge could occur. In Figure 2 region ED is the recharge area and AE the discharge area. The line that separates the recharge and discharge areas is called the hinge line or midline and is at point E.

A recharge area can be defined as that portion of the drainage basin in which the net saturated flow of groundwater is directed away from the water table. In a discharge area, there is a component to the direction of groundwater flow near the surface that is upward. A

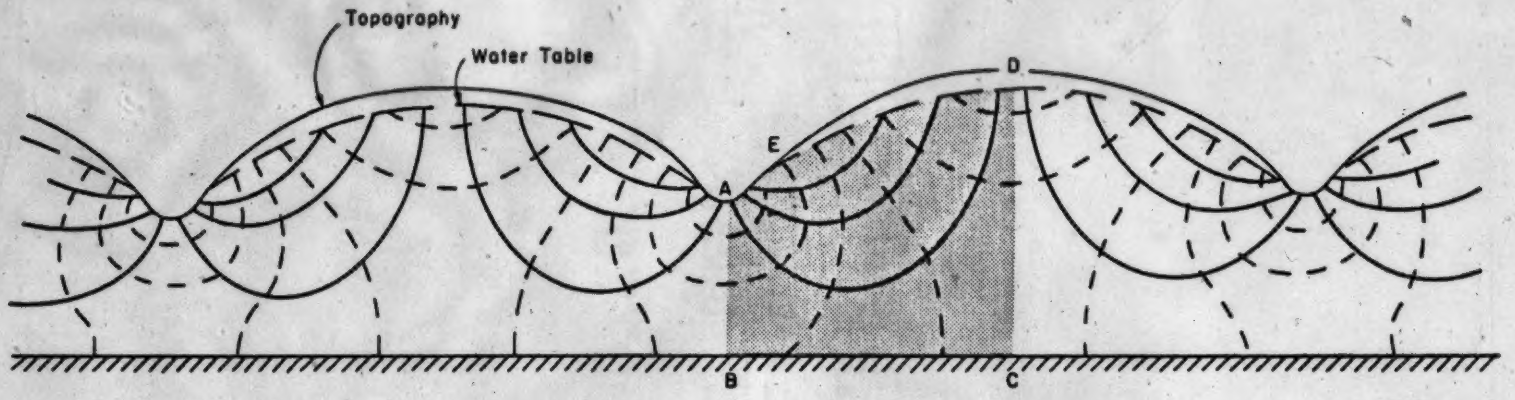


Figure 2: Groundwater flow net in a two-dimensional vertical cross section through a homogeneous, isotropic system bounded on the bottom by an impermeable boundary (After Hubbert 1940).

discharge area can be defined as that portion of the drainage basin in which the net saturated flow of groundwater is directed towards the water table (Freeze and Cherry 1979). In a recharge area the water table usually lies at some depth; in a discharge area, it is usually at or very near the surface.

Three distinctly different types of flow systems can occupy a basin. These are local, intermediate, and regional systems. A local system of groundwater flow has its recharge area at a topographic high and its discharge area at a topographic low that are located adjacent to one another. The major characteristic of an intermediate system of groundwater flow is that, although its recharge and discharge areas do not occupy the highest and lowest elevated places in a basin, one or more topographic highs and lows may be located between them. A system of groundwater flow is considered to be regional if its recharge area occupies the water divide and its discharge area lies at the bottom of a basin. Figure 3 shows all three of these systems together.

The boundaries between flow lines do not signify an abrupt change in any of the physical properties of flow but relatively rapid changes in the chemical composition of the waters across the boundaries could occur. This is expected because of the different locations of the recharge areas and the different lengths of the flow paths for the different systems. The amount of recharge water is directly proportional to the area of recharge, so the greatest flow densities occur in shallow depths of the local systems (Tóth 1962). The amount of flow decreases rapidly with depth and with the transition from the local to the intermediate region, reaching the minimum in the regional system (providing the latter exists).

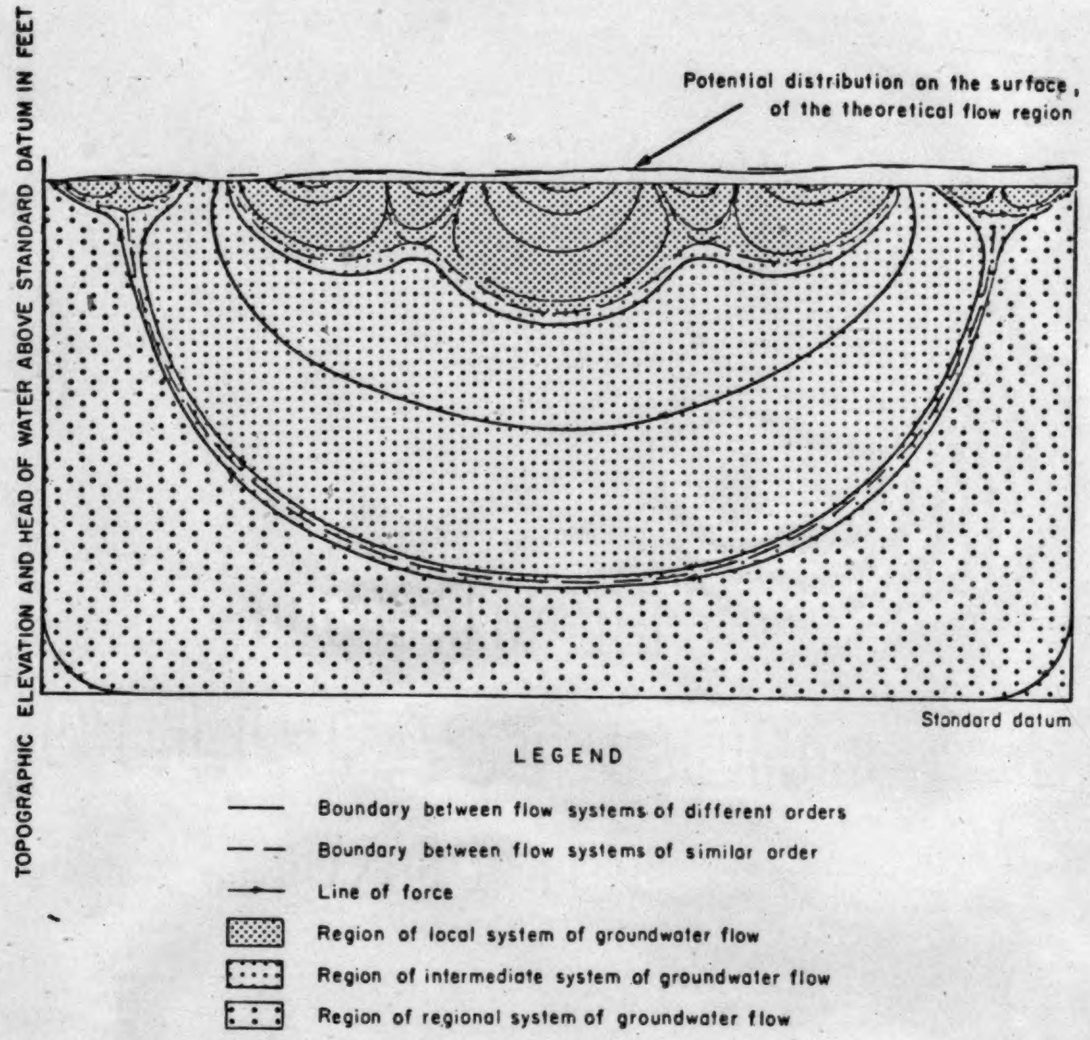

TOPOGRAPHIC ELEVATION AND HEAD OF WATER ABOVE STANDARD DATUM IN FEET
Potential distribution on the surface, of the theoretical flow region
Standard datum
LEGEND
Boundary between flow systems of different orders
Boundary between flow systems of similar order
Line of force
Region of local system of groundwater flow
Region of intermediate system of groundwater flow
Region of regional system of groundwater flow

Figure 3: Theoretical flow distribution in a composite, homogeneous, and isotropic drainage basin (After Tóth 1963).

There are several factors which can affect the flow through these systems. As the depth of the flow region increases, the water movement slows down, which will probably result in higher mineralization of groundwater. A general increase in the slope of the valley flank will result in an increased lateral flow towards the bottom of the valley. Increasing topographic relief will increase the depths and the intensities of local flow systems. High permeability lenses in an otherwise homogeneous medium will act like a topographic high and may create local recharge and discharge areas.

Recharge areas are characterized by a lowering of the water level in piezometers as the depth to which these instruments are inserted, increases. Depending on the local slope of the land surface, water levels may drop, remain constant, or rise with increasing depth in discharge areas (Tóth 1963).

3. Movement of Moisture in the Unsaturated Soil Zone

Up to this point, groundwater flow has been discussed with respect to a saturated porous media, i.e. one in which all the voids are filled with water. Soils, especially those near the ground surface, are seldom saturated. Their voids are usually only partially filled with water, the remainder of the pore space being occupied with air. The flow of water under such conditions is termed unsaturated.

The simplest hydrologic configuration of saturated and unsaturated conditions is that of an unsaturated zone at the surface and a saturated zone at depth. The water table acts as a boundary between the two zones and a saturated capillary fringe usually exists above the water table. Figure 4 shows the groundwater conditions near the ground surface by depicting the saturated and unsaturated zones and a profile of mc versus

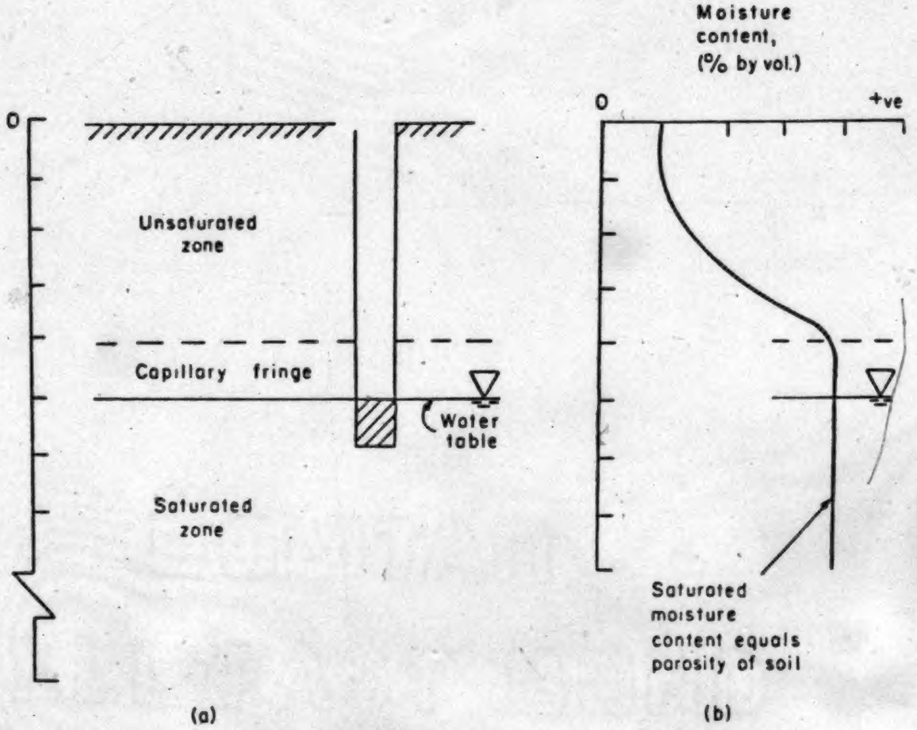

0
Unsaturated zone
Capillary fringe
Water table
Saturated zone
(a)
Moisture content, (% by vol.)
0
+ve
Saturated moisture content equals porosity of soil
(b)

Figure 4: Groundwater conditions near the ground surface.
(a) saturated and unsaturated zones
(b) profile of moisture content versus depth (After Freeze and Cherry 1979).

depth.

Depending upon the position within the groundwater flow system and atmospheric conditions, moisture may move downwards, upwards, or laterally. In so doing, ions as part of the dissolved solids may be transported from one location to another within the soil body.

The process of infiltration is the entry into the soil of water made available at the ground surface, together with the associated flow away from the ground surface within the unsaturated zone. This is the downward flow mentioned above. Rainfall, when it reaches the ground surface, infiltrates the surface soils at a rate that decreases with time. The decline is caused mainly by the filling of the soil pores by water. As the water moves downward away from the soil surface, it takes with it ions, and in so doing transports materials from one area in the soil body to another.

Upward movement of water in the unsaturated zone occurs by capillary movement of moisture. In the capillary fringe, water moves upwards from the water table into the unsaturated zone. The capillary pores within the fringe are saturated, but the pressure heads are less than atmospheric. This zone is also called the tension-saturated zone. By this type of moisture movement, materials may be moved upwards towards the soil surface.

The lateral movement of water may also occur in the unsaturated soil zone. It may occur as a perched water table on top of a slowly permeable or impermeable layer, or throughout the soil body as a result of moving from areas of high to low moisture content.

4. The Chemistry of Groundwater

The chemical quality of groundwater is determined by the kind and amount of chemical matter dissolved in the water. The primary controls on the amount of dissolved solids in the groundwater are: the chemical character of the water as it enters the zone of saturation; the distribution, solubility, and adsorption capacity of the minerals in the deposits; and the time in which the water is in contact with the rocks (Back 1966). Time itself is dependent on the porosity and permeability of the rocks and the flow path of the water.

When relatively pure rainwater infiltrates in the soil, dissolved carbon dioxide dissolves calcium carbonate and magnesium carbonate from the soil by the following reactions:

$$CO_2 + H_2O + CaCO_3 \rightarrow Ca(HCO_3)_2 \rightarrow Ca^{+2} + 2HCO_3^-$$
$$CO_2 + H_2O + MgCO_3 \rightarrow Mg(HCO_3)_2 \rightarrow Mg^{+2} + 2HCO_3^-$$

After the water has infiltrated further into the formation, and has been in contact with the sediments for a long period, slow attack of sedimentary minerals such as gypsum and feldspars predominates. The addition of bicarbonate occurs only by solution of the more soluble carbonates of which magnesium carbonate predominates. The enrichment of magnesium with respect to calcium may occur along the flow path. Sulfate content usually increases, possibly from the oxidation of sulfides. Sodium content also usually increases.

As water flows further into the formation, the processes of chemical dissolution continues. There is also an increase in the amount of total dissolved solids, predominately of chloride and sodium.

From the above, the conclusion is that the types of solids being added to groundwater depends on the type of flow system it is in. Local flow systems become enriched in calcium and bicarbonate and are responsible for adding calcidic material to a soil system. The groundwater only travels a short distance and depth into the ground. Intermediate flow systems have as dominant ions calcium, magnesium, sulfate, and bicarbonate. Materials this system adds to the soil are comprised of gypsum, epsomite, and dolomite. A regional flow system is very deep flowing and the major ions in the groundwaters are sodium, chloride, and sulfate. The materials usually deposited are sodium sulfate and sodium chloride. Much more sulfate is put into solution than chloride so sodium sulfate predominates.

In terms of the types of materials that the groundwater is flowing through the following is true for the Interior Plains region, especially where underlying bedrock is of marine or brackish water origin. The Interior Plains are also where Solonetz soils are commonly found. Till is the parent material which dominates in magnesium and calcium contributions while bedrock dominates in sodium contributions. Therefore soils receiving discharge waters from a local system will be high in calcium and magnesium while those receiving water from a regional flow system will be high in sodium.

5. Groundwater and Solonetzic Soils

The role of groundwater has always played a very important part in studies related to Solonetzic soils. Kovda (1939) found that crustal Solonetz formed by rising groundwater and that Solonetz formation followed Gedroyts concepts. His studies revealed that Solonetz soils with distinct sodium concentrations close to the soil surface had relatively shallow water tables which were from four to eight meters deep. He discovered that the salt concentrations decreased as one moved from the soil surface towards the water table. Solonetz soils free of soluble salts in their lower horizons had a groundwater table at fifteen to twenty meters and salt concentrations increased with depth in the profile. Kovda stated that the salts were raised from the groundwater by capillarity and surface tension and crystalized upon evaporation.

Florya and Stoika (1958) in their study found that when the water table was three to five meters deep, there was an accumulation of water in the soil profile and the content of soluble salts increased. When the water table was lower, there was practically no salt accumulation.

As mentioned previously, Arshad and Pawluk (1966) found Solonetz soils to occur in relatively flat lying groundwater discharge areas where the capillary rise from a permanent water table was sufficient to maintain a high salt level in the lower B horizons. Bowser et al. (1962 a and b) found evidence to indicate that the majority of Solonetz soils in Alberta were maintained at this stage of development by the presence of either permanent or temporarily perched water tables, associated with the proximity of bedrock to the surface.

Groundwater was found by Rode (1962) to play a very important role in the process of solonetzization. His process involved the alternate resalinization and desalinization of a soil profile while the water table was being constantly lowered until the soil profile contained sufficient sodium and had been sufficiently leached of the majority of the other soluble salts to cause solonetzic properties to form. Rode stated that the upward movement of salts and water from the groundwater into the soil profile and its subsequent removal by leaching, was responsible for Solonetz formation.

Maclean and Pawluk (1975) found broad differences between soils at high elevations and those on lower slopes. They believed these differences could be explained by groundwater flow which had depleted salts from beneath the high elevations and increased the quantities of sodium and magnesium sulfates and bicarbonates near the ground surface, close to topographic depressions. In the upland areas, soil differences reflected differences in the depth to the water table. Chernozemic soils were confined to areas where the water table depth exceeded two meters for most of the year. Where the water table was within one half of a meter to the surface and where discharging groundwaters were saline, Alkaline and Saline Black Solonetz soils predominated. Black Solonetz soils predominated where discharge occurred but the water table was at least one half of a meter beneath the surface.

Groundwater is an important factor in salt accumulation processes, because it accumulates the soluble weathering products from large areas; transports (transmits) the salt content of deep subsurface waters, geological deposits and/or of soil layers into the top horizons; and impedes the leaching of salts derived from local weathering and/or irrigation waters (Varallyay1974). Varallyay felt that groundwater was the main secondary salt source, especially in low lying, poorly or very poorly drained areas, where horizontal flow was very slow and the resulting stagnant character afforded the possibility of a gradual increase in concentration. In these areas the water table was near the surface so the capillary flow could transport relatively large quantities of water and soluble salts from the groundwater to the overlying horizons where the active root zone was concentrated. Under such conditions, salt affected soil could develop not only in arid regions but also under relatively humid climates. Salt accumulation from the groundwater was also found to occur if a larger quantity of groundwater and soluble salts entered the soil profile than could be leached out during a certain period. This situation would occur as a result of the following circumstances:

1. The result of water movement through the soil profile (upward and downward flow).
2. The result of the water movement through the soil profile when it was downward and the excess quantity of water filtrating downward was not enough for the leaching of the accumulated salts, because the solubility of salts entering the profile from the groundwater changed.
3. More or less universal changes took place in the soil's solid phase under the effect of filtrating solutions and so the downward movement of water and salts was limited to a certain extent (Varallyay1974).

A study by Elgalaby and Naguile (1965) showed that the critical depth and salt concentration, defined as the depth and salt concentration at which the processes of soil salinization started, especially in the surface horizons, dependedupon the depth and salinity level of the groundwater, climate, and the irrigation regime. They found that the critical depth of groundwater could be modified by the concentration of salts in the groundwater. The higher the salt concentration of the groundwater, the deeper the critical depth of the groundwater. It followed that the higher the groundwater level, the lower the critical salt concentration.

Climate is important in determining the critical depth and salt concentration, especially in the humid, cooler areas of the world. In the hotter, drier areas, depth to groundwater is not so crucial since evaporation always produces a net upward movement. In humid, cooler areas, where infiltration is not restricted, there is considerable downward water movement from the soil surface. In these areas the depth to groundwater is critical in the formation of Solonetz soils.

From the above information it can be seen that groundwater plays a very important role in the formation of Solonetzic soils. Groundwater is responsible for the addition and removal of ions that are responsible for solonetzic characteristics observed in soils.

III. THE ROLE OF SALTS IN GENESIS OF SOLONETZIC SOILS

1. Introduction

The original, and to some extent the direct, source of all the salt constituents found in soils are the primary minerals found within these soils and in the exposed rocks of the earth's crust. These primary minerals form the primary source of salt and are an end result of the weathering of rocks. Rocks contain sodium, potassium, magnesium, and calcium in the form of silicates. Chlorides are rarely seen in rocks while sulphur is present mainly as insoluble sulphides which may be transformed into soluble sulphates after oxidation (van der Molen 1975).

Most commonly, the direct source of salts to the soil is surface and groundwaters. All of these waters contain dissolved salts, the concentration depending on the salt content of the soil and geologic materials with which the water has been in contact. These waters add salts to the soil under natural conditions, such as when they flood low-lying land or when groundwater rises close to the ground surface (Richards 1969).

In terms of the salts present in Solonetzic soils, the solution in these soils, although relatively low in soluble salts, has a composition different from that of normal and saline soils. The soluble salts that occur in these soils consist mostly of various proportions of the anions chloride and sulfate and the cations sodium, calcium, and magnesium (Richards 1969). Constituents that ordinarily occur only in minor amounts are the anions bicarbonate, carbonate, and nitrate and the cation potassium.

Solonetzic soils are often referred to as sodic soils. These soils are characterized by an exchangeable-sodium-percentage of greater than 15 and a conductivity of less than 4 mmhos/cm at 25°C in a saturation extract. The pH readings of these soils usually range between 8.5 and 10. These soils correspond to Hilgard's "black alkali" soils. Sodic soils differ from saline and saline-sodic soils in the following manners:

	Saline	Saline-Sodic	Sodic
E.C. mmhos/cm	> 4	> 4	< 4
pH	< 8.5	8.5	8.5-10
E.S.P.	< 15	> 15	> 15

(Richards 1969)

2. Salts and Solonetzic Soils

Most researchers agree that sodium is the cation responsible for the processes leading up to the development of a Solonetzic B horizon. The accumulation of sodium ions is in the solid and/or liquid phases of the soil, ie. the presence of dissolved sodium salts in the soil solution and/or exchangeable sodium ions in the soil adsorption complex. These two phenomena are directly or indirectly responsible for the low productivity of sodic soils. The high salt concentration of the soil solution is toxic to plants and it limits their water and nutrient uptake, metabolism, and results in physiological deterioration. The high sodium saturation of the soil causes increased hydration, dispersion and peptization of soil colloids, structural destruction, aggregate fracture and consequently results in poor physical and hydrophysical properties (low available moisture range, swelling, low infiltration rate, low saturated and unsaturated hydraulic conductivities, etc.) (Szabolcs 1976).

While there is agreement that sodium is the cation responsible for solonetzic properties, there are differing opinions as to the amounts of sodium it takes to initiate the process.

Gedroyts (1912) and de Sigmond (1938) first postulated that the content of exchangeable sodium was important in the solonetzization process. Gedroyts stated "that all the special properties of Solonetzic and Solonetz soils which distinguish them from non-solonetzic soils are produced by adsorbed sodium" (Buylov 1965). He further stated that after excess salts were removed from a soil, exchangeable sodium caused the dispersion of humic and mineral colloids. Upon drying, a columnar structure developed in the black, dispersed B horizon. de Sigmond attempted to place solonetzization on a quantitative chemical basis when he defined a leached alkali soil (equivalent to a Solonetz) as one in which the soluble salt content was below 0.1 - 0.15% and where adsorbed sodium made up ten to fifteen percent of more of the exchangeable cations (de Sigmond 1926).

In the United States, Solonetz soils are those with a natric horizon. The United States Department of Agriculture (1967) described a natric horizon as one with prismatic or more commonly columnar structure and more than fifteen percent saturation with exchangeable sodium. The National Soil Survey Committee of Canada (1963) defined Solonetzic soils as "soils with solonetzic or disintegrating solonetzic B horizons which have an exchangeable base status in which fifty percent or more is sodium and magnesium or which have more than twelve percent exchangeable sodium and usually have saline subsoils". Szabolcs (1965) reported that even an amount of exchangeable sodium as small as five to eight percent of the total cation exchange capacity of the soil influences the properties. MacGregor and Wyatt (1945) found the exchangeable sodium of thirteen solodized brown soil profiles to average seven percent of the exchangeable bases present. They also found that for six profiles from the Black Soil Zone, the average was twelve percent. Therefore, different percentages of exchangeable sodium saturation have been reported to cause the adverse properties associated with Solonetzic soils.

Dahlman (1965) investigated the influence of strain on the shear strength parameters for calcium, magnesium, potassium, and sodium modifications of a lacustrine clay. Dahlman found that an ESP of 7% was sufficient to develop the zeta potential so that a dispersed sodium soil-water system resulted. He also found that sodium modifications created the most dispersed soil system. Calcium and magnesium created a more flocculated system and potassium created a system in between the sodium and calcium and magnesium types.

Work was done on calcium clay systems with various percentages of adsorbed sodium by Hamilton (1961). The result was that a marked increase in plasticity characteristics arose when 28% of the available exchange positions were filled with sodium.

Following the statement by de Sigmond in which he provided a chemical definition for Solonetz soils, a considerable number of soils with Solonetz morphology but with very small percentages of exchangeable sodium were reported (Kelley 1934; Kellogg 1934; Bentley and Rost 1947; Mitchell and Riecken 1937; and Ellis and Caldwell 1935). These low sodium soils were uniformly high in exchangeable magnesium (50 - 70%) and low in exchangeable calcium (25 - 35%) which encouraged investigators to refer to them as "Magnesium Solonetz". Riecken (1941) formulated a theory for the dominance of magnesium in the exchange complex, and found that this element did not occupy the role usually taken by sodium in the morphological and chemical development of a Solonetz. Kelley (1934) pointed out the important point that magnesium clays were much more colloidal than calcium clays. Sushko (1933) concluded that the amount of exchangeable magnesium present, correlated with the degree of solodization of the soil profile, but he did not associate its presence with the evolution of the profile. Gedroyts noted in several papers (1921-1923, 1932, 1955) that the solonetzic properties in soils could be produced by adsorbed magnesium and he related the compaction of the upper horizons of the compact Chernozems of the Kulan to the high content of adsorbed magnesium in these soils (25 - 30% of total exchangeable cations). Antipov-Karatayu studied the problem of the effect of adsorbed magnesium on the solonetzic properties of soil and concluded that the solonetzic properties of soil became stronger under the influence of adsorbed magnesium (Buylov 1965). Buylov in his study found that exchangeable magnesium together with sodium played a role in enhancing solonetzic properties of soil. Arshad (1964) found high exchangeable magnesium in soils where solonetzic processes were weak or absent. He felt that the magnesium was probably a result of the replacement of exchangeable sodium by magnesium in the soil solution during the early stages of solodization. From this brief review of the opinions of several authors on the role of adsorbed magnesium, it can be seen that this subject is controversial.

There are many types of sodium salts which contribute sodium to Solonetz soils: sodium chloride, sodium sulfate, sodium carbonate, and sodium bicarbonate being the dominant ones implicated.

Most researchers in North America and many in Europe have found that conditions for development of Solonetzic soils are a result of the adsorption of sodium by the soil from a solution of neutral sodium salts (sodium chloride, sodium sulfate). Ivanova found that the development of a typical Solonetz from a neutral Solonchak occurred when there was a prevalence of sodium chloride and sodium sulfate (Tyurin et al. 1967). Khan and Webster (1968) found sodium sulfate carried by groundwater rising within a few feet of the soil surface to be the principle soluble salt in Solonetzic soils near Vegreville. A well defined upward movement of sulfate from the water table with retention in the soil, was greatest near the surface. Arshad and Pawluk (1966) found Solonetz soils to be salinized primarily with sodium sulfate and that the presence of these salts resulted from a temporary infusion by capillary water.

Some theories on the genesis of Solonetzic soils claim that their development lies in the adsorption of sodium by the soil from solutions of alkaline sodium salts, especially soda, and to a lesser extent from solutions of neutral sodium salts (Tyurin et al. 1967). The reason is that adsorption of sodium from its alkaline salts proceeds far more intensively than any adsorption from neutral sodium salts.

Ivanova conducted intensive research into the problem of soda (sodium carbonate and sodium bicarbonate) formation and its role in Solonetz formation. In doing so, she formulated yet another theory for the genesis of Solonetzic soils. Ivanova stated that the simplest and most likely mechanism for Solonetz development was the salinization of the soil with sodium, the latter being adsorbed from its alkaline or soda solutions, in a process of periodic salinization and partial desalinization of the soil. She felt that this was the prevalent mechanism for genesis when weakly mineralized groundwater occurred at a relatively shallow depth. V.A. Kovda in his studies on the Barbara Lowland in Siberia, explained the genesis of Soda Solonetz in precisely the same terms (Tyurin et al. 1967).

On the basis of the foregoing, six major theories of soda formation are proposed:

1. Weathering of igneous and sedimentary rocks containing sodium. They are usually of the Cretaceous age and are calcareous (Tyurin et al. 1967).

2. The release of exchangeable sodium from the soil adsorption complex according to Gedroyts reaction:

   a. $2Na - clay + H_2CO_3 \rightarrow 2H - clay + Na_2CO_3$

   b. $2Na - clay + CaCO_3 \rightarrow Ca - clay + Na_2CO_3$

   c. $2Na - clay + Ca(HCO_3)_2 \rightarrow Ca - clay + 2NaHCO_3$

3. As a result of reduction of sulfates by sulfate-reducing bacteria in the presence of humus. The following reactions assume the organic matter to be cellulose (Rode 1962).

   a. $3Na_2SO_4 + C_6H_{10}O_5 \rightarrow 3Na_2S + 6CO_2 + 5H_2O$

   b. $Na_2S + H_2CO_3 \rightarrow H_2S + Na_2CO_3$

   c. $Na_2S + CaCO_3 \rightarrow CaS + Na_2CO_3$

4. Hilgard Reaction: This is a reversible reaction consisting of the reaction of the carbonate of lime and magnesium on the chlorides and sulfates of the sodium in the presence of an excess of carbon dioxide. This reaction takes place more readily if only sulfates are present since gypsum that is formed is less soluble than calcium chloride. It crystalizes out in solution and hence prevents any reverse reaction (Hilgard 1918).

   a. $CaCO_3$ (or $MgCO_3$) + 2NaCl $\rightleftharpoons$ $CaCl_2$ ($MgCl_2$) + Na_2CO_3

   b. $CaCO_3 + Na_2SO_4 \rightarrow CaSO_4 + Na_2CO_3$

5. Mineralization of plant residue. On the degradation of dead plants, the liberated cations will become bound to free carbonates and form calcium, potassium, and sodium carbonates (Bobkov 1969).

6. As a result of desalinization of Solonchaks by improving drainage, removing the source of surface and groundwater or by an increase in precipitation which involves a change in climate. As a result of the removal of excess salts, the soil colloids become highly dispersed and the soil takes on an alkaline reaction. This alkalinity is attributed to the hydrolysis of the sodium from the exchange complex by the following scheme (Arshad 1964):

   a. $\text{Na - soil} + H_2O \rightarrow \text{H - soil} + NaOH$

   b. $2NaOH + CO_2 \rightarrow Na_2CO_3 + H_2O$

   or $\text{Na - soil} + CaCO_3 \rightarrow Na_2CO_3 + \text{Ca - soil}$

Soda is a salt of a strong base and a weak acid, is therefore subject to hydrolysis and causes an alkaline reaction. The pH can range from ten to eleven (Rode 1962). Due to the dispersed state of the soil and the alkalinity, certain soil forming processes occur, and a Solonetz forms.

The formation of soda and the development of Solonetzic soils by soda has been documented in Europe and Russia, but it is not reported in North American literature as being important in Solonetz formation.

IV. THE ROLE OF SEASONAL CHANGE IN GENESIS OF SOLONETZIC SOILS

Past and present research has concentrated on the formation of Solonetzic soils during the warm months of the year under evaporating conditions, while little is known of the significance of processes during the cold seasons. In general, the genesis of Solonetzic soils is thought of as occurring during the warm spring and summer months. During these months, groundwater is able to move upwards into the soil profile by either capillary movement or as discharging groundwaters to the soil surface. This upward movement of water, brings with it considerable supply of salts. During these warm months, net upward movement of water and evaporation is much greater than the downward movement of water, so the salts are concentrated near or at the soil surface. When rain does occur, it leaches out some of the salts, and in so doing decreases salt concentrations to levels where the process of solonetzization is initiated.

Da-lin and Zheng-quan (1979) used columns of loosley packed sandy soil of different heights placed in a salt solution of labelled $Na_2S^{35}O_4$ to simulate groundwater, and under evaporating conditions studied salt and water movement into the soil profile. The movement of soluble salts was studied using radioisotopic methods. Results showed that the content of soluble salts in the soil phase as well as the salts in the water phase, rose with capillary water. The capillary water rose to the surface of the column where it evaporated and left behind salt precipitates. The thickness of the salt concentration layer increased as the evaporation increased.

Hassan and Ghaibeh (1977) found that evaporation from soils often caused a considerable loss of soil water and also involved the hazard of toxic buildup of salts in the root zone. The salts were brought upwards by capillary water and there was an increase of salt content near the soil surface due to evaporation. This study was done on homogeneous columns in the presence of a shallow water table.

The phenomenon of soil water transfer related to temperature gradients has been reported by many researchers. Bouyoucos (1915) showed in the lab a large transfer of water from warm to cold regions of soil samples. Lebedeff (1927) found that an upward movement of 6.6 cm of water into near-surface soil horizons occurred during the winter (October to March) of 1914 and 1915 in Odessa, Russia. Taylor (1962) and Cary and Taylor (1962) showed that if temperature gradients were present in a system, water moved from the region of high to a region of low temperature in response to matric potential differences. Meyer (1960) observed in both the lab and field, that groundwater levels (water tables) fell during the winter with reduced air temperature and rose approximately in the same amounts in the spring with increasing air temperature. Meyer felt that the large amounts of water transferred could not have occurred by the mechanism of vapour transfer only, but that water movement occurred as liquid or film flow. Schneider (1961) also observed relationships of air temperature and groundwater levels, and attributed winter water table decline to upward movement of capillary moisture to the frost layer. From his lab work, Jumikis (1962) concluded that soil water transfer in the vapor phase was relatively ineffective when compared with soil water transfer by film or liquid flow mechanisms. Willis et al. (1964) overwinter studies showed a drop in water table levels and explained the drop as being associated with the depth of frost. The loss of water from groundwater storage was accompanied by increases in soil moisture in the frost zone above the water table. Results obtained by Ferguson et al. (1964) clearly indicated that water moved to a frozen zone under field conditions when water in the unfrozen zone was held at low tensions. The authors stated that the amount of movement probably depended on available soil water, the temperature of the frozen zone, duration of the frozen period, and the physical properties of the soil.

The presence of an ice phase in the soil was found to enhance the amount of water transfer under temperature gradients (Hoekstra 1966). The chemical potential of unfrozen absorbed water in frozen soils, if in equilibrium with ice, was independent of the total water content. Consequently, no equilibrium water content was reached and the water content in frozen soil changed continuously. Therefore, water flow in a frozen soil took place under temperature gradients through the films of unfrozen water, but the rate of water transport decreased with decreasing temperatures below 0^oC (Hoekstra 1966).

Cary (1966) felt that thermal moisture transport could be thought of as the moisture flux through soil which could arise solely as a result of a temperature gradient. Moisture would flow through the soil from warmer to cooler areas in the vapor and liquid phase. Cary found that one of the most striking soil moisture flow phenomenon which developed along with a significant thermal gradient, occurred during the winter months as moisture moved up into the frost zone.

Frost heave tests on uniformly frozen Devon silt were conducted by Mageau and Morgenstern (1980) to study moisture migration characteristics of frozen soil. From these tests it was found that moisture could be transported through the unfrozen film under the influence of a temperature gradient. The rate of flow was governed by the permeability of the frozen soil and the suction force within the frozen fringe. These two parameters of the frozen soil, were in turn, functions of the soil temperature. For the clayey silt test, it appeared that the temperature at which the rate of moisture migration slowed to an insignificant level was near -2^{o}C.

It has been found that soluble salts as well as water are able to move upwards towards the frozen zone during the winter. Cary and Mayland (1972) conducted an experiment where salt and water movement were measured in unsaturated frozen soil columns. They found that under natural conditions in the field, temperature gradients always existed, and that liquid water tended to move from warmer to cooler areas. A spontaneous vapor pressure gradient in this same direction was fixed by the temperature of the ice phase. While some movement was in the vapor phase, most of the flow was in the unfrozen liquid films. Since the films contain high concentrations of soluble salts, it is apparent that salt could also move from warmer to cooler areas in the unsaturated frozen soil.

Soluble salts may be carried by mass flow in the liquid films, by diffusion along salt concentration gradients, and by thermal diffusion along the thermal gradients. The results of Cary's and Mayland's experiment, showed that both water and salt moved from the warmer to cooler areas in the soil and that cation exchange reactions and salt solubilities at high concentrations could affect the movement. The results also suggested that mass flow of dissolved salts in a liquid film of water was the principle transfer mechanism and that both vapor and salt diffusion were only sometimes significant. Thermal diffusion did not seem to be important.

Cary et al. (1979) followed up their earlier experiment with another in which they investigated the theory that both solute and solution could move upwards in response to a temperature gradient. They used field observations of soil temperatures as well as the simultaneous water and solute redistribution in soil with ice present to investigate the theory. The authors found that water in frozen soil flowed from high to low temperatures and from high to low salt concentrations.

van Schaik and Rapp (1970) found the translocation of water during the winter from shallow water tables to the freezing zone in irrigated areas to be important. They stated that thermally induced moisture flow could possibly transfer salts upwards and salinize the surface soil. Truss (1959) found that the migration of salts and soil moisture in the soils of Central Baraba had great seasonal variation. In the winter, moisture accumulated in the soil and when it was frozen, the salts were drawn upwards to the frozen layers. In the summer when the soil thawed and there was downward flow of water, salts were removed and the surface horizons desalinized.

Orlovski (1967) found that liquid water and soluble salts accumulated together in the frozen soil used in his study. He found that the main salt accumulations were calcium and magnesium sulfates and to a lesser extent, sodium sulfates followed by sodium, magnesium, and calcium chlorides. Bicarbonates were seldom present. He therefore believed that an important salt differentiation was produced by freezing.

From the foregoing it is obvious that there has been considerable work done on the flow of moisture caused by thermal gradients during the winter. Water moves upwards from the water table during the winter towards the frozen layer and brings with it soluble salts. The water freezes and the salts are deposited. In the spring when the frost melts leaching will occur and some of the soluble salts are removed. Once again, as was seen in the formation of Solonetz soils during the summer, conditions may easily arise which can effect the genesis of these soils. This was observed by Cary and Mayland (1972) who also noted the ability of this movement to form problem soils. They cited the example of a sulfate soil system that was uniformly wet in the fall and had a sodium to calcium and magnesium ratio just borderline to causing adverse conditions. On freezing, the calcium sulfate and magnesium sulfate precipitated out while the soluble sodium sulfate could, depending on the exchange reaction between the soil, move upwards to the surface with the winter-time migration of liquid phase water. Melting in the spring resulted in a uniform sodium to calcium and magnesium ratio near the surface, leading to dispersion, decreased infiltration and all the other problems associated with Solonetz soils. Therefore, it may be concluded that salt and water movement in a frozen soil can act to create a salt problem.

V. SUMMARY OF THE LITERATURE REVIEW

The literature review for this research project has dealt with various theories of Solonetz formation as well as the roles of groundwater, salts and season in their formation. In summary, Solonetz soils are formed by shallow groundwater moving upward into the soil pedon by capillarity or through discharge to the soil surface, and alternately salinizing and desalinizing the soil. Once a certain percent of exchangeable sodium has been achieved, profile development such as dispersion, formation of sodium humates, etc. can occur. In Alberta, sodium sulfate has been reported as being the principle salt responsible for Solonetz formation. Other sodium salts such as sodium chloride and sodium bicarbonate also occur, but in much smaller amounts. Season plays an important role in the development of these soils. One school of thought, is that the majority of Solonetz soil formation occurs during the summer months in areas where there is more upward movement of water than downward movement of water accompanied by considerable evaporation. Therefore, water moves upwards carrying with it soluble salts, and the salts are deposited at the soil surface by evaporation. More recent research indicates that these soils may be forming during the winter when both water and salts move upwards to the soil surface in response to a temperature gradient. The water freezes and the salts are deposited at the soil surface.

This research project will be concerned with salts, groundwater, and season in determining the nature of Solonetzic B horizon formation. The foregoing literature review provides a background upon which these investigations may be based.

SITE DESCRIPTION

I. LOCATION

Two sites were selected for this study on the basis of the type of soils present and their physiographic features. The first site referred to as the Beamer site, is situated thirty-five miles east of Edmonton, Alberta (S.E.-17-54-18-W4) near the town of Chipman. The second site, called the Paulencu site lies fifty miles east of Edmonton (S.E.-29-55-15-W4) near the town of Mundare. Both of the sites lie in East-Central Alberta, are mapped as Black Solonetz soils within the Black Soil Zone, and are characterized by undeveloped range land.

II. CLIMATE

The climate of the area in which the Beamer and Paulencu sites lie is continental and is characterized by relatively warm summers and cold winters. The mean summer temperature (May to September) is 13°C and July is the warmest month with an average temperature of 16°C. The mean winter temperature (November to March) is -9°C and both April and October each average 4°C. January is the coldest month of the year and averages around -14°C (Bowser et al. 1962).

An important feature of the continental climate in East-Central Alberta is that there can be large annual ranges in temperature. Over a thirty year period the mean July temperature varied over 9°C and the mean January temperature varied over 37°C at Edmonton (Koeppe 1931). Although there is variation in temperatures from year to year, extreme winter lows rarely fall below -40°C and extreme summer highs rarely go above 32°C.

Frosts are recorded at least once in each of the summer months. The average frost free period is 100 days and varies from 50 to 150 days.

Mean annual precipitation varies from 41 to 46 cm. In Edmonton, the past 75 years has averaged 45 cm with extremes of 23 and 76 cm (Bowser et al. 1962). In 75% of the years, the total precipitation was between 36 and 53 cm. June, July, and August are the months of highest rainfall, totalling an average of just greater than 23 cm. Precipitation from November to March is extremely light; monthly totals rarely exceed 2.5 cm and most falls in the form of snow. Approximately 70% of the total precipitation falls as rain and the rest as snow. The average annual snowfall at Edmonton is just above 127 cm and varies from 25 to 227 cm (Bowser et al. 1962).

The wind velocity averages just under 16 kph and there is little variation over the year. Winds of gale force are experienced approximately two times per year. Winds prevail from the northwest. The frequency of thunderstorms reported in Edmonton are twenty per year.

The East-Central area of Alberta is considered as having a dry to moist sub-humid climate.

III. VEGETATION

In the East-Central part of Alberta where the sites for this study are located, 2/3 of the land is cultivated. However both sites used in this study are on land that is believed not to have been cultivated but is used for grazing.

The vegetation of both areas consists of grasses, shrubs and some trees. The dominant grasses are: slender wheat grass (*Agropyron trachycaulum* (Link) Malte. var. typicum Fern.); western wheat grass (*Agropyron smithii* Rybd.); wild barley (*Hordeum jubatum* L.):

Nuttal's salt meadow grass (Puccinellia nuttalliana (Shultes) Hitche.); and Sandbert's blue grass (Poa secunda Presl.). Some wire grasses such as Juncus spp. are also present in fair numbers.

The principal species of shrubs and herbs present are: common wild rose (Rosa woodsii Lindl.); dogwood (Cornus stolonifera Mich.); beaked willow (Salix bebbiana Sarg.); Russian pigweed (Axyris amaranthoides L.); and Canada thistle (Cirsium arvense L.).

Widely scattered stands of aspen and balsam poplar are found at the sites. The aspen (Populus tremuloides Michx.) favours the slightly drier sites and the balsam poplar (Populus balsamifera L.) the slightly more humid areas.

The Beamer site has a large number of the above trees in a stand as the overstory and shrubs as well as many grasses make up the understory. The stands of poplar and shrubs are more dense at the site where the water ponds in the spring. The Paulencu site has very few trees and those present are very stunted. The vast majority of the vegetation at this site consists of grasses. Plate 1 and 2 are illustrations of the vegetation at the Paulencu and Beamer Sites.

IV. TOPOGRAPHY AND DRAINAGE

East-Central Alberta is part of the Plains region and lies within the drainage basins of the North Saskatchewan and Beaver Rivers. The important tributaries of the former river are the Battle and Vermilion Rivers and of the latter, the Sand River. Elevations in the area in general decrease from west to east and the topography is gently undulating to rolling with some extensive flat-lying areas. The lowest elevation, about 1,600 feet above sea sevel, is in the North Saskatchewan River valley where the river crosses the Alberta-Saskatchewan boundary.

Plate 1: Vegetation at the Beamer site.

a. Some shrubs and trees.

b. Some native grasses.

COLOURED PICTURE

Plate 2: Vegetation at the Paulencu site.

a. Some stunted poplar trees.

b. Some native grasses.

COLOURED PICTURE

The highest elevation in East-Central Alberta is over 2,700 feet above sea level but most of the area lies between 2,100 and 2,400 feet above sea level (Le Breton 1963).

The Beamer site is located on level to gently undulating topography. It is well-drained all year round except during the spring when water accumulates in depressions and marshy conditions develop. The Paulencu site is also level, but unlike the Beamer site, depressional areas are lacking.

V. GEOLOGY

1. Surficial

The Beamer and Paulencu sites lie in a physiographic unit which is called the ground moraine area. Ground moraine is defined as a level to gently undulating till plain. The surface of the ground moraine in the area is gently undulating with a local relief of up to 20 feet.

Till is unsorted, unstratified sediment deposited by a glacier. In this study area, till makes up most of the ground moraine. The composition of the till varies from place to place due primarily to the nature of the underlying bedrock. Generally, however, it is of clay loam texture; it is slowly to very slowly permeable; and is usually quite sticky (Bowser *et al*. 1962). It contains gravels of Rocky Mountain origin, stones of Precambian origin, and fragments of coal, ironstone, shale and sandstone probably of local origin. There are also some limestone and dolomite erratics. All the till of the study area contain diffuse calcium and magnesium carbonates, usually making up from one to three percent of the content. The color of the till is usually brown near the surface. Between thirty-three and ninety-nine m below the surface the brown oxidized till grades into unoxidized till of grey to dark grey color.

In terms of the mechanical composition, the surface tills have the following average composition: sand 41%, silt 31%, and clay 28% (Bayrock and Hughes 1962). The clay-size fraction of the till contains a large percent of montmorillonite derived from the local Cretaceous bedrock which is sodium saturated. This gives the till a granule-like consistence. Other clay minerals also present are hydrous mica (illite), kaolinite, chlorite and fine grained quartz.

Concentrations of water-soluble salts vary regionally from 0 to 50 meq/100 gm in glacial till from Alberta. The presence of soluble salts also coincides closely with regions of Solonetzic soils from around the province. The principle salt present in till samples from Central Alberta is sodium sulfate, although a high content of magnesium sulfate is also evident in some samples. Although the distribution of soluble salts in tills in Alberta cannot yet be fully explained, it is evident that areas of high salt concentration do not coincide with specific bedrock formations, and there is no close relationship between bedrock formations and salt content of the till (Pawluk and Bayrock 1969). It is also evident that salt content shows no correlation with other chemical and mineralogical parameters of tills. High salt concentration in the till is related to groundwater discharge; it is a characteristic acquired by the sediment after deposition. The salt content of till is a function of climatic conditions, groundwater flow and surface drainage.

Much of the area being studied has been subjected to post glacial sorting. There are, therefore, local areas of lacustrine, alluvial and aeolian deposits. Some of the material is of relatively local origin: material that has been washed or otherwise carried out of adjacent till. Some of these areas, however, are composed primarily of calcareous material carried down from the mountains by post glacial stream action. Some of the landscape has been scoured by glaciation but little if any glacial drift has been left behind. In these instances, the underlying bedrock formations approach or may even form the landscape surface.

Both the Beamer and Paulencu sites have been subjected to post glacial action. Soils at the Beamer site have developed on lacustrine clay, while those at the Paulencu site have developed on weathered residual Edmonton Formation.

2. Bedrock

The bedrock formations in East-Central Alberta are entirely of late Cretaceous age and are mostly obscured by overlying deposits of glacial drift. Geologic maps of the area record the ascending stratigraphic successions as Lea Park Formation, Ribstone Creek Formation, Grizzly Bear Formation, Birch Lake Formation, Old Man or Belly River Formation, Bearpaw Formation and Edmonton Formation. Throughout most of the area, the near-surface bedrock is the Edmonton Formation, and it is not until one approaches the northeast, that the Bearpaw and Belly River Formations form the bedrock surface. Since this research deals with the Edmonton Formation only, this bedrock will be the one discussed in detail.

The upper surface of the Edmonton Formation has been highly dissected by erosion. The basic configuration was set in preglacial time; however, the surface was somewhat modified during and since glaciation of the area. The lower boundary of the formation is defined by its contact with underlying Bearpaw shale. Thickness of the Edmonton Formation is variable due to erosion on its surface, however the thickness ranges from about 140 to 190 meters and averages 170 meters (Kathal and

McPherson 1975). The formation has a regional northwest to southeast strike and a drop of a few tens of meters per kilometer to the southwest.

The Edmonton Formation consists mainly of soft-weathered, fine-grained clastic sediments deposited in fresh- to brackish-water environments. The predominant lithologies are pale-weathered, fine-grained, bentonitic sandstones and siltstones interbedded with and grading vertically and laterally into grey to brown, bentonitic, silty claystones. Coal and bentonite beds of variable thickness are present throughout the formation.

The average percentages of sand, silt and clay sized particles in the Edmonton Formation are 14%, 51%, and 35%, respectively (Locker 1973). The clay mineralogy of this formation, consists of approximately 65% montmorillonite, 25% illite and 10% kaolinite and chlorite (Locker 1973).

Soluble salts present in clays or fine-grained rocks affect the adsorbed ion complex and the electrolytes in the pore water system. The types and concentrations of cations that make up the salt content depends, among other factors, on the salt content of the original depositional medium and the movement and chemistry of subsequent groundwaters. Average values for the major cations in meq/100 grams are 11 for sodium, 34 for calcium and 9 for magnesium. An average cation exchange capacity is 35 meq/100 grams. These results show that calcium, sodium, and magnesium in that order of abundance are commonly present as ions in the pore water of the Edmonton Formation. Potassium is found only in negligible amounts. The cation exchange capacity is associated with the amount of montmorillonite present. It has been found that the distributions of the exchangeable cations vary with formations, rock types and localities. It has been found that sodium is higher in the eastern area of the formation where there is more montmorillonite present.

The Edmonton Formation has low permeability and in terms of a well yield, can yield commonly less than 5 gpm. It is suited to domestic and small stock supplies in terms of groundwater potential.

VI. GROUNDWATER GEOLOGY AND HYDROLOGY

1. Bedrock Aquifers

Supplies of groundwater from wells in this region may be sufficient to satisfy domestic and limited livestock requirements. This refers to quantities sufficient for rural or individual municipal household needs and that sufficient to supply about 20 to 30 head of cattle, some hogs and poultry. However, many of these wells may also be pumped dry under normal conditions of useage. There are very low yields for wells in this area (less than 5 gpm) and this is due to the groundwater sources being largely thin, fine grained sandstones of limited areal extent and low permeability. In terms of apparent transmissibility values for these bedrock aquifers, they are commonly less then 100 gpd/foot (Le Breton 1963).

2. Glacial Drift and Bedrock Channel Aquifers

Most of East-Central Alberta is covered by till containing water-bearing sand and gravel lenses. Only domestic supplies and limited livestock supplies of groundwater may be expected from such sources. Many wells terminating in the till yield only 200 to 600 gpd and frequently are reported to be pumped dry.

Large amounts of water may be obtained only from the granular materials that occur in spillways, stream-trench systems, outwash areas and in buried or partly buried preglacial river valleys. In each case, the well yield is dependant upon the aerial extent, thickness and permeability of the deposits. There is very little hydrological data on these types of aquifers so little can be said about them. The transmissibility for some surficial deposit aquifers are in the range of 1000 to 5000 gpd/foot. There are values for sand and gravel deposits in spillways, stream-trench systems and buried valleys.

3. Chemistry of Groundwaters

The total solids content for water from bedrock ranges from 300 to 6000 parts per million (ppm) and for water from glacial drift from 250 to 24,000 ppm. The average for both types of water is 1,200 ppm. In both cases, approximately 42.5% of the water has a total solids content less than 1,000 ppm and only 3% of bedrock sources and 12% of drift sources contain less than 500 ppm (Le Breton 1963). Most of the groundwater in the area falls withinthe saline category, saline referring to total solids content in excess of 1000 ppm. According to the United States Public Heath Service Standards, the water in the area can be considered as unsuitable for human consumption. However, by provincial health standards in Alberta, the limit for total solids is 1,600 to 2000 ppm.

The concentration of chloride in bedrock and glacial drift groundwater is very low. The bedrock water and some of the drift water are notable for low total dissolved solid contents. The sulfates range from 0 to 1,960 ppm and average 300 ppm for bedrock water and range from 0 to 12,300 ppm and average 400 ppm for drift water. The iron content ranges from 0 to 5.3 ppm and averages 0.8 ppm in bedrock water and ranges from 0 to 5 ppm and averages 0.7 ppm in glacial drift water. In both types of aquifers, the iron is above the suggested limit of 0.3 ppm.

The hardness or calcium carbonate equivalent is low in bedrock and high in groundwater from drift. In bedrock aquifers it ranges from 0 to greater than 1000 ppm and averages around 300 ppm. In glacial drift groundwater hardness ranges from 0 to greater than 1000 ppm and averages around 600 ppm.

The alkalinity expressed as calcium carbonate, ranges from 600 to 900 ppm and is often the same as hardness for groundwater. If water is hard, the alkalinity is due to bicarbonates of calcium and magnesium but if it is soft, it is due to bicarbonates of sodium.

From the foregoing, it can be said that groundwater from bedrock aquifers is often of doubtful suitability because total dissolved solids are likely to be high and are composed largely of sodium bicarbonate. Groundwater from drift aquifers is more suitable and total dissolved solids are largely bicarbonates and sulfates of calcium and magnesium.

VII. SOILS

The sites of importance to this study are described in the Soil Survey Report of the Edmonton Sheet by Bowser et al. (1962). The soils of this map area have been classified according to the system of classification outlined by the National Soil Survey Committee of Canada (1960). There are four orders of soils which are found to be most abundant, and these are the Chernozemic, Solonetzic, Luvisolic, and Gleysolic orders of soils.

Nineteen soil series of the Chernozemic Order have been recognized in the Edmonton sheet area and these occupy a total of 4,465,760 hectares or 1/2 of the mapped area. They occur in the grassland and parkland regions and practically all are within the main Black Soil Zone. These soils are in general, good to excellent arable lands and are the most fertile soils of the area.

Soils of the Solonetzic Order occupy 2,235,350 hectares or 1/4 of the total mapped area, and sixteen soil series have been recognized. These soils occur as small patches throughout the Chernozemic soil areas and along a strip running north and south from Edmonton. The Solonetzic soils are from poor to good arable lands. The Alkali Solonetz and Solonetz soils are poor to fair; the Solodized Solonetz fairly good to good; and the Solod soils generally good. All the soils within this order have a Solonetzic B horizon of very low hydraulic conductivity, salt in the C horizon, and a chemistry that results in varying degrees of nutritional imbalances. These soils do not produce as well as Chernozemic soils and their production capacity varies from season to season.

Thirteen soil series in the Luvisolic Order occupying a total of 936,130 hectares have been recognized in the Edmonton sheet. These soils are tree covered with poplar and poplar-spruce associations and occur in the Grey Wooded Soil Zone on ground moraine. Luvisolic soils vary from non-arable to fairly good arable. All of these soils have a low amount of organic matter, are moderately to strongly eluviated and are usually deficient in some nutrients.

The Gleysolic soils occupy the poorly drained, usually depressional areas. All of these soils have limited use for agriculture but if drainage was provided, could become good arable land. Five soil series have been recognized and they occupy a total of 133,380 hectares.

The soil studied in this project is a Black Solonetz. Profile descriptions of this soil at each of the two sites are given in Tables 1 and 2. Illustrations of the two soil profiles can be seen in Plates 3 to 6.

Table 1: Profile description for the Beamer site.

Order: Solonetzic

Great Group: Solonetz

Subgroup: Black Solonetz

Ah	0 - 5 cm	Very dark gray (10YR 3/1) loam; moderate fine granular; friable; abundant fine and very fine random roots; clear irregular boundary with tonguing between columns; 1 - 7.5 cm thick.
Ahe	5 - 6 cm	Very dark grayish brown (10YR 3/2) loam; weak platy to medium and course granular; friable; abundant fine and very fine random roots; abrupt broken boundary; 0 - 3 cm thick.
Bntj1	6 - 14 cm	Very dark brown (10YR 3/2) clay; common, fine, faint, dark yellowish brown (10YR 4/4) mottles; strong very coarse, roundtop,columnar and massive; very firm; plentiful, fine and very fine oblique and vertical exped roots; gradual wavy boundary; 2 - 8 cm thick.
Bntj2	14 - 24 cm	Very dark brown (10YR 2/2) clay; some patches of organic staining; strong fine and medium blocky; very firm; few fine vertical and oblique, exped roots; gradual smooth boundary; 10 cm thick.
Bntj3	24 - 40 cm	Very dark grayish brown (10YR 3/2) clay; moderate fine to medium blocky; firm to very firm; few fine random roots; clear smooth boundary; 16 cm thick.
Bsa	40 - 58 cm	Very dark grayish brown (10YR 3/2) clay; weak fine blocky to massive; firm; numerous pockets of gypsum crystals 3 cm in diameter; very few, fine, random roots; gradual smooth boundary; 18 cm thick.
Csa	58 - 67 cm	Very dary grayish brown (10YR 3/2 - 2.5 Y 3/2) clay; very weak irregular blocky to massive; firm; numerous crystal chambers 3 cm in diameter; very few, fine, random roots; clear smooth boundary; 9 cm thick.
Cs1	67 - 90 cm	Very dark grayish brown (10YR 3/2 - 2.5 Y 3/2) clay; massive; firm; numerous fine salt crystals 2 - 5 mm in size; clear smooth boundary; 23 cm thick.
Cs2	90 - 108 cm	Gray (2.5 Y 3/2) varved fine sandy silt and very dark grayish brown (10YR 3/2) clay; many, continuous distinct yellowish brown (10YR 5/4 and 10YR 5/6) mottles in silt bands; clear smooth boundary; 19 cm thick.
Cs3	108 - 132 cm	Dark grayish brown (10YR 3/2 - 2.5 Y 3/2) heavy clay; massive; firm; few salt crystals; gradual smooth boundary.
Cs4	132 - 164 cm	Dark grayish brown (10YR 3/2 - 2.5 Y 3/2) heavy clay; massive; very plastic and sticky; 32 cm thick.

Table 2: Profile description for the Paulencu site.

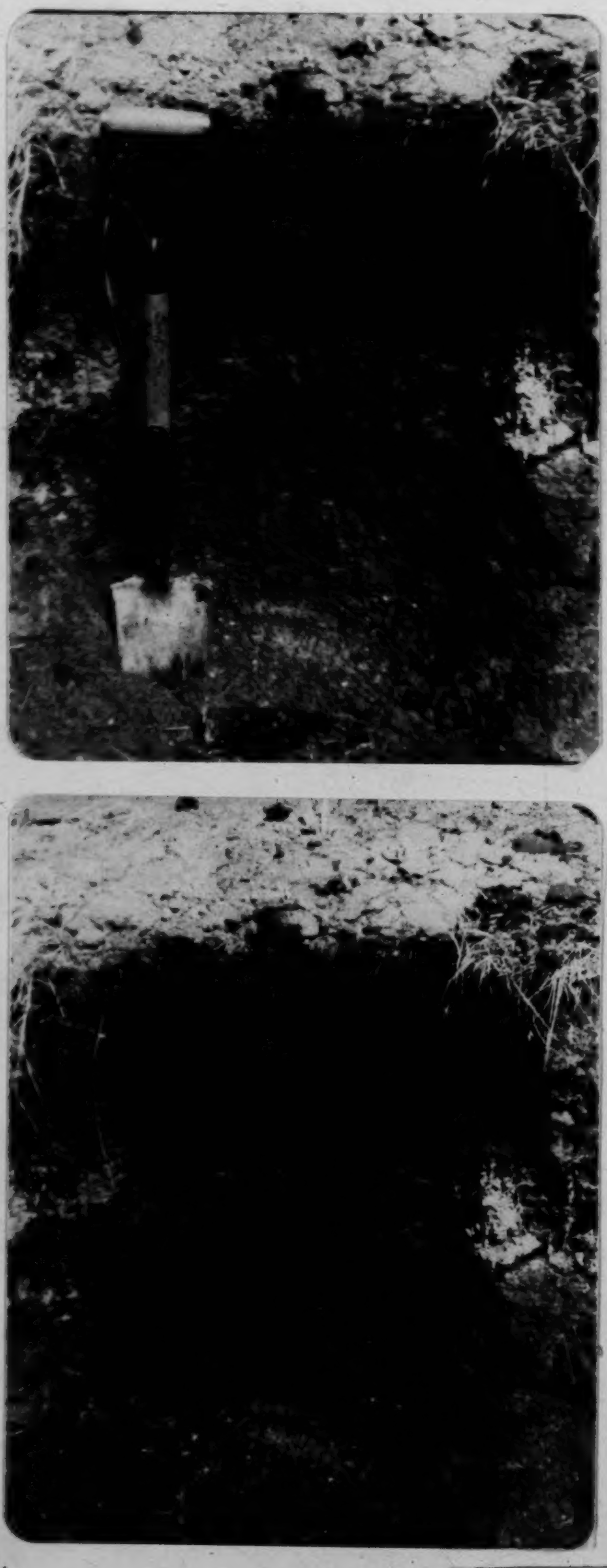
Order: Solonetzic

Great Group: Solonetz

Subgroup: Black Solonetz

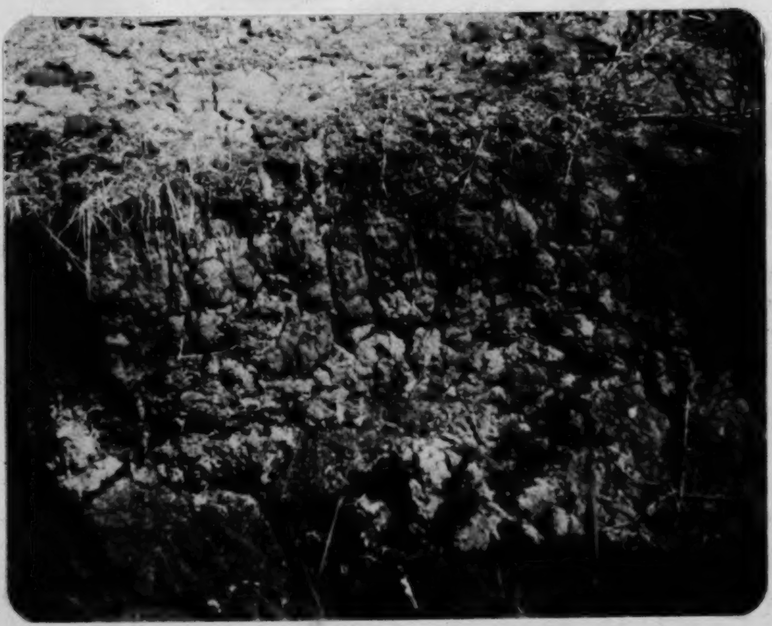
Ah	0 - 4 cm	Very dark brown (10YR 2/2 (m)) clay loam; moderate fine granular; friable to slightly firm; abundant, very fine and fine random roots; clear, irregular boundary with wide shallow tonguing between columns of solonetz; 1 - 6 cm thick.
Ahe	4 - 6 cm	Very dark grayish brown (10YR 3/2 - 4/2 (m)) loam; weak fine granular; friable; abundant very fine and fine random roots; abrupt broken boundary; tonguing and thickest between columns of solonetz; 0 - 2 cm thick.
Bntj1	6 - 11 cm	Dark grayish brown (2.5 Y 4/2 (m)) clay; common, medium, distinct, dark yellowish brown (10YR 4/4) mottles; some organic very dary grey (2.5 Y 3/1) staining; strong, very coarse, round top columnar and massive, very firm; plentiful, very fine and fine, oblique and vertical exped roots; gradual wavy 2 - 5 cm thick.
Bntj2	11 - 23 cm	Very dark gray (10YR 3/1 (m)) clay with some very dark grayish brown (2.5 Y 3/1) organic staining; strong, fine and medium blocky; very firm; few, fine random exped roots; gradual, wavy boundary; 8 - 12 cm thick.
Bntj3	23 - 43 cm	Dark gray to dark grayish brown (2.5 Y 4/1 - 4/2 (m)) clay; massive to strong blocky; very firm; very few, fine, random roots; clear wavy boundary; 8 - 21 cm thick.
Bsa	43 - 63 cm	Dark gray to dark grayish brown (2.5 Y 4/1 - 4/2 (m)) clay: massive to weak medium and fine blocky; firm to very firm; gradual smooth boundary; 20 cm thick; saline with numerous pockets of gypsum crystals.
Csa1	63 - 83 cm	Dark gray to dark grayish brown (2.5 Y 4/1 - 4/2 (m)) clay; massive; firm; gradual smooth boundary; 20 cm thick; saline with numerous pockets of gypsum crystals.
Csa2	83 - 123 cm	Very dark grayish brown (2.5 Y 3/2 (m)) clay; massive; very plastic and very sticky; abrupt, wavy boundary; 40 cm thick; saline with a few pockets of gypsum, below water table and transition to sandstone below.
IIC1	123 - 135 cm	Very dark grayish brown (2.5 Y 3/2 (m)) clay; dark yellowish brown (10YR 4/6) loamy sand; many coarse distinct reddish yellow (7.5YR 6/6) mottles; banded weathered sandstone with clay and loamy sand bands; friable; gradual smooth boundary; 12 cm thick.
IIC2	135 - 160 cm	Very dark grayish brown (2.5 Y 3/2 (m) clay; dark yellowish brown (10YR 4/6) loamy sand; many coarse distinct reddish yellow (7.5YR 6/6) mottles; banded weathered sandstone with clay and loamy sand bands; friable; gradual smooth boundary; 12 cm thick.

Plate 3: Photos of Black Solonetz at the Beamer site.



COLOURED PICTURE

Plate 4: Photos of Black Solonetz at the Beamer site.



a. Profile of Black Solonetz when dry.

b. Some round tops removed from the pit.

COLOURED PICTURE

Plate 5: Photos of Black Solonetz at the Paulencu site.

COLOURED PICTURE

Plate 6: Photos of Black Solonetz at the Paulencu site.

a. Profile of Black Solonetz when dry.

b. Some round tops in the bottom of the pit.

COLOURED PICTURE

VIII. ASSOCIATED RESEARCH

Dr. G. Webster from the University of Alberta, in Edmonton, Alberta, is also doing research at the Beamer and Paulencu sites. His research deals directly with the effects of different amelioration techniques on Solonetzic soils. He is investigating the effects of practices such as deep plowing and the application of chemical amendments such as gypsum.

Other associated research has been done all around the Vegreville area by such people as Dr. Cairns, Dr. MacLean and L. Leskiw.

Deep plowing experiments have been conducted by Alberta Department of Agriculture under the supervision of J. Hermans. Deep plowing has seemed to increase yields in the Vegreville area, when compared to control plots in the same field.

FIELD INSTRUMENTATION AND MONITORING SALT AND WATER FLUXES

I. INSTRUMENTATION

At both Beamer and Paulencu sites similar instrumentation was installed. The instrumentation installed at the sites included the following:

1. seven salinity sensors
2. three piezometers
3. one water table well
4. one neutron probe access tube
5. one temperature probe

These instruments can be seen in Plate 7.

1. Salinity Sensors

The seven soil salinity sensors (Soil Moisture Equipment Corporation Cat. No. 5100-A) were supplied completely assembled, calibrated, and ready for installation. An individual data sheet accompanied each sensor. The sensors were designed to be used with the Soil Moisture Equipment Corporation. Cat. No. 5500 Salinity Bridge. When used with the salinity bridge, the sensors permitted the direct read-out of soil solution conductivity in millimhos automatically corrected to a standard temperature of 25°C. The sensors are of coaxial design with a cable coming out from the end of the sensor. They are designed to fit into a 2.5 cm diameter hole cored into the soil.

Seven salinity sensors were placed at 10, 20, 30, 46, 61, 76, and 91 cm depths. The procedure followed for placement was to make a 2.5 cm hole to the desired depth using an Oakfield hand sampler, then

Plate 7: Instrumentation at the Beamer and Paulencu sites.

a. Instrumentation at Beamer's

- i. Top two cans cover piezometers.
- ii. Farthest can to the right is the water table well cover.
- iii. Second can from bottom is the temperature probe.
- iv. Can at bottom is access tube for neutron probe.
- v. Pit is in the background.
- vi. Salt cells are to the left of the access tube.

b. Instrumentation at Paulencu's

- i. Top three cans cover piezometers.
- ii. Can farthest to the left is the water table well cover.
- iii. Lowest can is the temperature probe.
- iv. Plastic bag covers the salt cells.
- v. Neutron probe access tube is to the far left of the salt cells but cannot be seen.

COLOURED PICTURE

inserting the sensor into the hole. Once the sensor reached the bottom of the hole a small diameter rod was used to press it securely with the face of the electrolytic element against the soil surface. The holes were then back-filled and gently but firmly packed down. When installing the sensors, it was essential that the exposed surface of the electrolytic element was in intimate contact with the soil. It is only through this contact that the soil solution can permeate the porous ceramic of the electrolytic element allowing ions to migrate freely between the soil and the element.

After sensors were installed in the field routine measurements of soil solution conductivity could be made by simply inserting the polarized plug at the end of the sensor lead wire, into the sensor receptacle on the panel of the salinity bridge. An intercept setting dial and slope-thermistor setting dial were adjusted to the values marked on the plug of the sensor. After balancing the bridge, the conductivity of the soil solution at 25^{0}C could be read out directly on the conductivity scale of the bridge.

2. Piezometers

Three piezometers were installed at each site in order to measure the direction of groundwater flow. The piezometers were inserted at 4, 6, and 8 meter depths.

The piezometers consisted of an outer 7.9 cm diameter casing of polyvinyl chloride (pvc) tubing inside of which was a 1.3 cm diameter polyethylene tube. The outer tubing acted as protection for the inner tube, which was the tubing in which the depth to groundwater was measured.

The piezometers were installed using a truck-mounted coring device.

An auger was mounted on a truck to dig down to the required depth. Once the required depth was achieved, the pvc tubing was inserted into the hole to keep dirt from falling into it. Once the outer tubing was in place, sand was put in the bottom of the hole. A 6.3 cm ceramic tube with the polyethylene tubing attached to it was then lowered into the hole. Sand was then placed in the hole to completely surround the ceramic tube. The pvc tubing was then pulled up so the ceramic tube would be exposed to the surrounding soil. A 50:50 mixture of bentonite and cement was placed on top of the ceramic tube to act as a seal to retard downward movement of water. The hole was also sealed at the soil surface with this mixture.

3. Water Table Well

The water table wells consisted of a 4 meter long, 7.9 cm diameter pvc tube which was perforated throughout the lower 3 meters. The hole for the well was 3.6 meters deep and was bored using a truck-mounted auger. Once the pvc tube was inserted into the bore, it was back-filled with sand up to 1 meter from the soil surface and then sealed with a bentonite-cement mixture.

4. Access Tube

Access tubes used for the measurement of soil moisture with a Nuclear-Chicago Model P19 Depth Moisture Probe were made by hand augering a hole to a depth of 137 cm. A standard steel tube was then placed into the hole to the augered depth. The tube was sealed tightly at the soil surface using a bentonite-cement mixture.

The Depth Moisture Probe is designed to measure the moisture content in soil from the surface to a depth of 61 m. It is used with the Model 2800 Portable Scaler. Moisture readings were taken in 15 cm increments to a depth of 137 cm from the soil surface. Readings were taken over one minute intervals and done in duplicate.

5. Temperature Probe

The temperature probe was installed by coring a 5 cm hole with an Oakfield Soil Sampler. The probe was then embedded in a rod made of plaster of paris, protected with tape, and then lowered down into the cored hole. The holes were backfilled with the original soil material. Thermistors making up the probe were so placed that temperatures were obtained in 2.5 cm intervals from 0 to 91 cm and in 10 cm intervals from 91 to 183 cm. The type of probe used was a Soil Test Thermistor Temperature Probe (6160).

II. MONITORING

Measurements were taken at each of the sites on a weekly basis from May 17 to November 17, 1978 and from April 1 to November 19, 1979. Readings were taken bi-weekly from December 1, 1978 to March 17, 1979 and monthly from November 19, 1979 to March 4, 1980. Measurements were changed to bi-weekly and then to monthly during the winter months because very little change occurred.

Weekly, bi-weekly, and monthly monitoring consisted of reading the seven salt cells; taking neutron probe measurements in 15 cm increments from 15 cm to 137 cm; taking temperature readings in 2.5 cm intervals from 0 to 19 cm and in 10 cm intervals from 91 to 183 cm; and measuring the depth to groundwater in the water table wells and piezometers. This was done at both the Beamer and Paulencu sites.

III. SAMPLING

Soil samples were taken each time the instrument measurements were recorded from May 1979 to March 1980. Samples were acquired using an Oakfield Soil Sampler when the ground was not frozen and a coring truck when it was frozen. Samples were taken in 10 cm increments from 0 to 81 cm.

A pit was dug at each site in order to obtain a complete profile description. Samples were taken from each horizon, for soil chemical and physical analyses.

Water samples were also collected from the piezometers and water table well.

IV. USE OF DYE INDICATORS

Two types of dyes were used in this research. The first is called Orange G and is the disodium salt of benzene-azo-2-naphthol-6,8-disulfonic acid. This dye was put in the 8 meter piezometers at each site on July 20, 1979. The purpose of adding this dye was to see if water was moving upwards from a depth of 8 meters, towards the soil surface. Upward movement of this dye was monitored by taking groundwater samples from the water table well on a weekly basis, and checking to see if the dye was present. This dye can be detected at very low concentrations by using a Spectrophotometer with a blue lamp at a wavelangth of 420 nm. The absorption maxima for Orange G is between 476 and 481 nm.

The second dye is a fluorescent dye called Uranine and is a fluorescein sodium salt. It was applied to the soil surface on July 15, 1979 and November 19, 1979 in plexiglass tubes. Each site received two plexiglass tubes: one was 31 cm high and had a funnel on the end of it and the other was 15 cm high and had no funnel. Figure 5 shows the tubes used in the field to add the Uranine. One hundred and twenty-five grams of Uranine were added to each of the tubes in both July and November. This dye was also added to soil columns (one from each site) set up in the laboratory to show if infiltration and/or throughflow was taking place in the soils under investigation.

Plate 8: Photos of plexiglass holders used to apply Uranine in the field.

a. Funnel plus 31 cm high plexiglass tube.

b. Plexiglass tube that is 15 cm high and has no funnel. The orange color is the Uranine.

COLOURED PICTURE

CHEMICAL AND PHYSICAL ANALYSES

Soil samples were weighed, oven dried for an average of two days at 105°C and then reweighed in order to obtain their percent moisture content. Samples were then ground to pass through a 2 mm mesh sieve and stored in glass jars.

Groundwater samples were collected directly into nalgene bottles out in the field.

I. WEEKLY VARIABILITY IN SOLUBLE SALT PROFILE AND GROUNDWATER SAMPLES

The following analyses were done weekly on the soil and groundwater samples.

1. Soluble Salts

A 1:5 soil-water extract (12 gm of soil to 60 ml of water) was prepared and then placed on the shaker overnight. In the morning, each extract was centrifuged on a low-speed and then high-speed centrifuge and then filtered under vacuum. The samples were stored in a fridge in nalgene bottles for further analyses.

a. Ca^{+2}, Mg^{+2}, Na^{+} and K^{+}

The above cations were determined using a Perkin-Elmer Atomic Absorption Spectrophotometer Model 503. Dilutions of 1:10, 1:100, and 1:1000 were made of each of the solutions.

b. HCO_3^{-} and CO_3^{-2}

Bicarbonate and carbonate contents were determined by titrating each solution with a standardized .01 M HCl solution with an automatic titrator.

The endpoint used for carbonate was 8.3 and bicarbonate was 4.0.

c. SO_4^{-2}

The turbidometric method was used to determine sulfate (Standard Methods for the Examination of Water and Wastewaters, 13th Edition, 1971, pg. 334 to 335). The procedure has been modified in that Sulfa. ver. LV powder pillows were substituted for barium chloride. These pillows have been used with success by the Departments of Geology and Soil Science at the University of Alberta.

d. Cl^-

Samples were tested for chloride by adding a few drops of silver nitrate to approximately 5 ml of solution. No chloride was detected in any samples so a further quantitative analysis was not necessary.

2. pH

The pH of each sample was determined by using the 0.01 M $CaCl_2$ method (McKeague, J., Ed. 1978. Manual of Soil Sampling and Methods of Analysis. pg. 66 to 67).

3. EC

The electrical conductivity of each solution was determined by using a YSI Model 31 Conductivity Bridge.

II. SOIL PROFILE CHARACTERIZATION

Samples from the horizons of each of the two soil profiles of interest to this study were analyzed for the following in order to obtain a complete characterization.

1. Soluble Salts and pH

The soluble salts and pH were determined as has already been described for the weekly measurements.

2. Percent Organic Matter

Organic carbon was determined by wet oxidation using the modified Walkly-Black method (McKeague, J., Ed. 1978. Manual of Soil Sampling and Methods of Analysis. pg. 115 to 117).

3. CEC and Exchangeable Cations

The CEC and exchangeable cations were determined by using NH_4OAc at a pH of 7 (McKeague, J., Ed. 1978. Manual of Soil Sampling and Methods of Analysis. pg. 115 to 117). The exchangeable cations were determined using a Perkin-Elmer Atomic Absorption Spectrophotometer Model 503.

4. Total N

Total nitrogen was determined using the semi-micro Kjeldahl method without precautions to include NO_3^- and NO_2^{-2} (McKeague, J., Ed. 1978. Manual of Soil Sampling and Methods of Analysis. pg. 125).

5. $CaCO_3$ Equivalent

Calcium carbonate equivalent was determined by using the method as outlined in the paper, "A Simple Titrimetric Method for Determination of Inorganic Carbon in Soils", by L. Bundy and J. Bremmer. A five gram sample of soil was treated with 2M HCL at room temperature for 16 to 24 hours in a stoppered bottle containing 2M KOH in a small beaker. The CO_2 released from carbonates by this treatment was determined by titration of the KOH solution with standard HCL.

6. Field Capacity and Wilting Point

The FC and WP of the profile samples were determined by using pressure plate extraction at 1/3 and 15 bars. This method is described on pages 45 to 46 in the Manual of Soil Sampling and Methods of Analysis, 1978, J. A. McKeague, Ed.

7. Particle Size Analysis

The percentages of sand, silt, and clay were determined on each horizon of the soil profiles. The hydrometer method was used (McKeague, J., Ed. 1978. Manual of Soil Sampling and Methods of Analysis. pg. 15 to 25).

8. Exchangeable Acidity

Exchangeable acidity was determined by using the $BaCl_2$ - Triethanolamine method (McKeague, J., Ed. 1978. Manual of Soil Sampling and Methods of Analysis. pg. 83 to 84). This procedure provides a direct measure of exchangeable acidity to pH 8.

RESULTS AND DISCUSSION

I. SOIL PROFILE CHARACTERIZATION

The results of chemical and physical analyses performed on samples from the Beamer and Paulencu sites are listed in Tables 3 to 5. The data are similar to those reported in the literature for Solonetz soils elsewhere in the province (Reeder and Odynsky 1964, Arshad and Pawluk 1966, Leskiw 1971, Toogood and Cairns 1978, and Maclean 1974).

1. Beamer Site

Results of the ammonium acetate extraction (Table 3) show calcium as generally the dominant extractable metallic cation throughout the soil pedon, except for the upper part of the B horizon where higher concentrations of magnesium and sodium are present. In general, the concentrations of each of the major cations increase with depth. These same trends have been reported by others (Toogood and Cairns 1978, Leskiw 1971). The exchangeable calcium to exchangeable sodium ratio is less than ten in all of the B horizons. The requirements are therefore met to classify the Solonetzic B horizons as Bn horizons (Canada Soil Survey Committee, Subcommittee on Soil Classification 1978).

The total exchangeable cations (TEC) figures rise dramatically in the lower part of the pedon (Bsa to Cs4) and is due to the presence of soluble salts. Above the horizons of salt accumulation the cations removed are largely exchangeable. Throughout and below the layer of accumulation ions present exist both as soluble salts in pore spaces and exchangeable ions adsorbed onto the soil colloids. During the ammonium acetate extraction for exchangeable cations, ions are also removed through

Table 3: Extractable cation analyses for two Solonetzic soils.

Sample	NH$_4$OAc Extractable Cations				Sum of TEC	NH$_4$OAc Extractable CEC	Exchange Acidity	pH	ESP
	Ca^{+2}	Mg^{+2}	Na^{+}	K^{+}					
		(me/100 gm)			(me/100 gm)	(me/100 gm)	(me/100 gm)		(%)
Beamer:									
Ah	10.6	5.5	3.0	1.4	35.5	57.7	15.0	4.8	5
Ahe	4.3	3.6	4.0	0.4	21.5	36.2	9.2	4.8	11
Bntj1	6.2	9.2	8.7	0.3	28.6	36.7	4.2	5.8	24
Bntj2	10.0	12.0	12.2	0.3	35.9	38.9	1.4	7.3	31
Bntj3	21.5	2.7	14.3	0.4	39.5	36.4	0.6	8.2	39
Bsa	60.5	14.2	16.0	0.4	91.1	34.0	-	8.1	47
Csa	78.6	13.1	16.3	0.3	108.3	31.4	-	8.4	52
Cs1	67.2	13.1	17.7	0.4	98.4	35.5	-	8.4	50
Cs2	41.0	9.8	14.2	0.3	65.3	25.3	-	8.4	56
Cs3	77.5	12.2	19.7	0.4	109.8	36.1	-	8.1	55
Cs4	50.7	11.3	18.6	0.4	81.0	36.9	-	8.1	50
Paulencu:									
Ah	5.2	4.1	5.4	0.5	28.0	45.8	12.8	5.0	12
Ahe	3.6	3.7	4.7	0.5	21.1	34.4	8.6	5.0	14
Bntj1	4.2	8.5	9.6	0.4	28.7	36.2	6.0	5.4	27
Bntj2	5.5	10.9	13.2	0.5	32.7	36.7	2.7	6.4	36
Bntj3	7.7	14.5	18.8	0.6	42.4	45.7	0.8	7.3	41
Bsa	70.1	18.1	24.5	0.6	113.3	55.2	-	7.4	44
Csa1	59.5	19.1	28.1	0.6	107.7	60.4	-	7.4	47
Csa2	62.5	17.0	26.2	0.5	106.2	51.2	-	7.3	51
IIC1	3.2	6.7	17.8	0.8	28.5	27.0	-	7.1	66
IIC2	7.9	7.1	18.1	0.8	33.9	27.9	-	7.0	65

the dissolution of some salts in the pore space, since salts present are soluble in an electrolytic solution (Black ed. 1965). As a result, when salts are present such as in the Bsa to Cs4 horizons of this pedon, values for the TEC increase markedly and include both exchangeable and soluble cations.

Calcium predominates in the salt layer since it is the least soluble and mobile constituent. When calcium salts are brought into the soil pedon by groundwater, they precipitate out on drying, forming horizons of salt accumulation.

The cation exchange capacity (CEC) as determined by ammonium saturation is highest in the Ah horizon and remains fairly consistent throughout the rest of the pedon. CEC values are high in horizons which have high organic matter and clay content (Arshad and Pawluk 1966).

In general, pH values are lowest in the A and upper B horizons. These values increase with depth in the pedon and range from strongly acid in the upper part of the profile to alkaline in the parent material. This change in pH with depth has been reported in the literature as being typical of many Solonetz soils (Reeder and Odynsky 1964, Arshad and Pawluk 1966, Canadian Soil Survey Committee 1978).

Both hydrogen and aluminum are exchangeable acid-generating cation species. Usually both are present in acidic horizons and are referred to collectively as "exchange acidity" (Buol _et al_. 1973). This exchange acidity is caused almost completely by aluminum ions (Coleman and Thomas 1964). The pH ranges from 4.8 to 5.8 in the acidic surface horizons in this profile. At these levels sufficient exchangeable aluminum is present to affect plant growth significantly (Kamprath 1967).

The acid surface horizons and alkaline sub-horizons are formed by the process of solonetzization (Gedroyts 1912). Once a pedon has been desalinized and the ratio of exchangeable calcium to sodium is less than ten, sodium clays disperse producing a hard, massive Bn horizon. This horizon is impermeable to water movement and therefore a perched water table develops. This results in conditions favourable for hydrolysis of the sodium ions adsorbed onto the colloidal clay fraction. Both exchangeable hydrogen and sodium hydroxide are produced, the latter being soluble and highly alkaline and the former less soluble and acidic (Bowser 1962). Therefore, the hydrogen remains near the surface creating an acidic pH while the sodium hydroxide is leached downwards to create an alkaline pH. The exchangeable hydrogen on the clay results in further hydrolysis where aluminum from the octahedral layer is cleaved off and occupies an exchange position. Silica is released and precipitates to form a white silicious coating on mineral grains.

Exchangeable sodium percentage (ESP) values vary from 5 to 56% throughout the pedon and reach a maximum in the B and C horizons. These values are greater than those cited in the literature (12 to 15%) as being necessary for solonetzization to begin (de Sigmond 1926, Gedroyts 1912). The ESP values are also sufficiently high to place the pedon within the Solonetzic Order of classification (National Soil Survey Committee of Canada 1963, United States Department of Agriculture 1967).

Sodium sulfate is the principle soluble salt found in the B and C horizons (Table 4). Only trace amounts of sodium bicarbonate are found. Concentrations of calcium and magnesium sulfate are high in the Bsa and Csa horizons and are otherwise low. High concentrations of sodium sulfate are also evident. These results agree with those reported by Khan and Webster (1968).

Calcium carbonate is absent in the A horizon but increases with depth in the profile to reach a maximum in the Bsa and Csa horizons.

Table 4: Soluble salt analyses.

Sample	Water Soluble Salts						SAR	CaCO$_3$ Equivalent
	Ca^{+2}	Mg^{+2}	Na^{+}	K^{+}	SO$_4^{-2}$	HCO$_3^{-}$		
	(me/100gm)							(%)
Beamer:								
Ah	0	0	1.0	0	1.0	0.5	5.0	0
Ahe	0	0	0.7	0	1.0	0.3	3.5	0.1
Bntj1	0.1	0.1	0.9	0	1.0	0.2	3.0	0.3
Bntj2	0.1	0.1	1.7	0	1.6	0.6	5.7	0.3
Bntj3	0.1	0.1	3.4	0	3.0	1.1	11.3	1.9
Bsa	11.9	4.5	14.4	0.1	31.9	0.6	5.0	4.4
Csa	10.8	3.9	14.4	0.1	27.9	0.6	5.3	4.6
Cs1	0.4	2.0	12.6	0.1	15.6	0.6	11.5	2.9
Cs2	0.3	0.2	5.6	0	6.4	0.6	11.2	3.5
Cs3	5.2	2.3	13.8	0.1	19.4	0.5	6.9	3.9
Cs4	0.5	0.5	10.5	0	10.3	0.9	15.0	2.7
Paulencu:								
Ah	0	0.1	1.2	0	0.8	1.5	4.0	0
Ahe	0.1	0.2	1.3	0	1.2	1.6	3.3	0
Bntj1	0.2	0.5	2.4	0.1	1.5	1.6	4.0	0
Bntj2	0.4	1.3	3.9	0.4	3.7	0.8	4.3	0
Bntj3	0.1	0.1	5.7	0	5.8	0.4	19.0	0
Bsa	3.2	2.1	16.5	0.1	27.7	0.3	10.3	0
Csa1	2.1	1.6	14.5	0.1	30.2	0.3	10.4	0
Csa2	6.1	3.4	22.0	0.1	38.8	0.2	10.0	0
IIC1	0.3	1.6	6.9	0.1	5.7	1.3	6.9	0
IIC2	0.1	0.7	10.5	0	10.7	0.2	15.0	0

Lime as well as sulfate salts concentrates in these two horizons and is often associated with Solonetz soils (Canadian Soil Survey Subcommittee 1978).

Sodium adsorption ratio (SAR) values vary between 3 and 15 and are highest in the lower B and C horizons. Therefore, sodium is quite active in exchange reactions with the soil in these lower horizons.

Organic carbon and nitrogen (Table 5) contents are highest in the A horizons and decrease progressively with depth. The amount of organic matter present in this pedon falls into the range of 15 to 20% reported for most mineral soils (Brady 1974).

This Black Solonetz has a high water holding capacity which is evident from the values given for field capacity (FC) and wilting point (WP). The percent moisture content (%mc) values are highest in the A horizons due to the presence of organic matter and the B and C horizons due to the high percentages of clay present (Bowser et al. 1962). The values given for the available moisture (AM) show the B horizons as retaining the greatest moisture.

The texture of this pedon grades from a loam in the A horizons to a heavy clay in the lower C horizons. The percent clay (%C) increases with increasing depth and has been reported in other literature (Arshad and Pawluk 1966). There is no accumulation of clay in the B horizon and no clay bulge is evident. As a result, the B horizon does not fulfill the requirements for a Bnt horizon and is classified as Bntj.

In summary, the Black Solonetz at the Beamer site may be characterized as having: calcium as the dominant exchangeable metallic cation; concentrations of cations which increase with depth; acidic surface horizons which grade to alkaline sub-horizpns; sodium sulfate as the

Table 5: Organic matter and physical analyses for two Solonetzic soils.

Sample	Organic C (%)	Total N (%)	F.C. (%)	W.P. (%)	A.M. (%)	Particle Size Distribution %S	%Si	%C	Texture
Beamer:									
Ah	22.4	1.1	60	47	13	38	48	14	L
Ahe	11.0	0.6	43	31	12	36	42	22	L
Bntj1	4.2	0.3	46	25	21	28	30	42	C
Bntj2	2.7	0.2	43	21	22	30	26	44	C
Bntj3	1.3	0.1	44	24	20	28	22	50	C
Bsa	0.7	0.1	35	18	17	32	14	54	C
Csa	0.7	0.1	33	16	17	28	16	56	C
Cs1	0.7	0.1	37	19	18	22	20	58	C
Cs2	0.6	0	31	17	14	28	32	40	C
Cs3	0.8	0.1	42	24	20	22	16	62	HC
Cs4	0.8	0.1	43	24	19	18	20	62	HC
Paulencu:									
Ah	16.3	0.5	50	38	12	52	30	18	L
Ahe	11.4	0.5	41	32	9	46	30	24	L
Bntj1	4.2	0.2	48	25	23	38	24	38	CL
Bntj2	2.8	0.1	50	24	26	38	38	34	CL
Bntj3	1.9	0.1	53	24	29	34	22	44	C
Bsa	0.9	0.1	54	28	26	26	10	64	HC
Csa1	1.0	0.1	59	35	24	26	10	64	HC
Csa2	0.7	0.1	56	32	24	34	12	54	C
IIC1	0.4	0	38	16	22	66	14	20	SCL
IIC2	0.4	0	35	15	20	62	16	22	SCL

predominant soluble salt; a high water holding capacity; a texture which grades from a loam to a heavy clay with depth in the profile; and an average ESP value of 38%.

2. Paulencu Site

Results of the ammonium acetate extraction (Table 3) show sodium as generally the dominant extractable metallic cation throughout the soil pedon, except in the Bsa, Csa1 and Csa2 horizons. In these horizons of salt accumulation, calcium is more abundant as has been explained under the Beamer section. Concentrations of all extractable cations increase with depth up to the parent material stratigraphic break. Results similar to these were reported by Cairns (1961).

The exchangeable calcium to exchangeable sodium values are less than ten in the B horizons. These horizons may therefore be classified as Bn horizons (Canada Soil Survey Committee, Subcommittee on Soil Classification 1978).

The TEC figures increase after the Bntj3 horizon up to the IIC1 horizon due to the dissolution of soluble salts in the pore spaces, by the ammonium acetate.

The CEC is lowest in the Ahe horizon and increases with depth. The highest CEC values are associated with large percentages of clay and organic matter (Arshad and Pawluk 1966).

The pH values are acidic in the A and upper B horizons and are slightly alkaline throughout the rest of the pedon. The pH values at this site are not as alkaline as those at the Beamer site but still follow the trends reported for Solonetz soils (Reeder and Odynsky 1964). This increase in pH with depth is due to the hydrolysis of sodium clays.

The acidity in this profile, like that at the Beamer site, is due mostly to aluminum. The values for pH range from 5.0 to 6.4 in the acidic horizons. Values in this range are a result of sufficient exchangeable aluminum present to significantly effect plant growth. At a pH of 6.4, only the very acid-sensitive crops are effected (Buol et al. 1973).

Values for the ESP vary between 12 and 66%: the percentages increasing from 12 to 65% with depth in the pedon. These values, like those at the Beamer site, are greater than the percentages cited for solonetzization and also allow this pedon to be classified in the Solonetzic Order (de Sigmond 1926, Gedroyts 1912, National Soil Survey Committee of Canada 1963, United States Department of Agriculture 1967).

The exchangeable acidity is highest in the surface horizons and decreases with depth. This high acidity near the surface is due to the presence of hydrogen and aluminum clays.

Sodium sulfate (Table 4) is the predominant soluble salt in this pedon except for the Ah, Ahe and Bntj1 horizons. In these horizons, sodium bicarbonate concentrations are high. Both salts have been described in the literature as being important to solonetzization (Tyurin et al. 1967). Both sodium and sulfate ion concentrations increase in the lower horizons, while the remainder of the ion concentrations remain generally the same. Calcium and magnesium salts are present in significant amounts in the Bsa, Csa1 and Csa2 horizons. Calcium carbonate does not appear in this pedon, so no lime accumulation occurs.

SAR values vary between 3.3 and 19. The highest value is found in the Bntj3 horizon.

Organic nitrogen and carbon contents (Table 5) reach a maximum in the A horizons and decrease progressively with depth. Organic matter at this site falls within the range of 15 to 20% which is normal for most mineral soils (Brady 1974).

A high water holding capacity as shown by the values for FC and WP occurs throughout this pedon. The highest moisture contents are correlated with organic matter and clay content (Bowser et al. 1962).

The texture of this pedon grades from a loam to a heavy clay within the parent material and is a silty clay for the material below. The %C increases with increasing depth and has been reported by others (Arshad and Pawluk 1966). Like the Beamer site, no clay bulge occurs in the B horizon, resulting in the classification as a Bntj horizon.

In summary, the Black Solonetz at the Paulencu site may be characterized as having: concentrations of cations which increase with depth; sodium as the dominant exchangeable metallic cation: acidic surface horizons which grade to alkaline sub-horizons; sodium bicarbonate as the predominant soluble salt in the surface horizons and sodium sulfate as the dominant soluble salt in the lower horizons; a high water holding capacity; a texture which grades from a loam to a heavy clay with depth in the profile; and an average ESP of 37%.

II. SOIL TEMPERATURE

Figures 5 to 8 illustrate the average monthly soil temperatures from May 1978 to March 1980. These figures are located in a folder on the inside of the back cover of this thesis. Similar trends exist at each site and are consistent with those cited in the literature (Brady 1974 and Baver et al. 1972).

During the month of May soil temperatures are highest in the surface horizons (11^{O}C) and decrease with increasing depth (2^{O}C). In June the same pattern occurs but both surface and subsoil temperatures have increased (18^{O}C and 5^{O}C respectively). All soil temperatures continue to increase, the temperatures in the subsoil approaching those in the surface horizons, until maximum values are reached in August. By September, the surface and subsoil temperatures are nearly equal. After September, all soil temperatures are cooler, the surface horizons cooling much faster than the subsoil horizons, so that temperatures at the surface are lower than those at depth. This cooling of the soil continues until April when soil temperatures once again, start to increase. At this point the annual cycle as described above, begins once again. (The extreme variations in temperatures at the 91 cm depth at the Paulencu site and the 33 cm depth at the Beamer site is likely due to thermistor malfunctioning).

This movement of thermal energy away from the soil surface during the spring and summer months and towards the soil surface during the fall and winter months occurs by conduction (Brady 1974). It is due to conduction that the subsoil changes tend to lag behind those to which the surface horizons are subjected. Changes that occur are always less in the subsoil. In temperate regions, surface soils in general are expected to be warmer in summer and cooler in winter than the subsoil, especially the lower horizons of the subsoil (Brady 1974). These trends were found to exist at the Paulencu and Beamer sites.

The information discussed above is well illustrated in Figures 9 and 10 (inside back cover). These graphs show a warming of the soil in March with temperatures reaching a maximum in July and August. Soil temperatures then start to decrease and reach a minimum in February. The cycle then repeats itself. It is apparent from these figures that the seasonal variation of soil temperatures is considerable, even at lower depths. The surface layers vary more or less according to air temperatures and therefore exhibit a greater fluctuation than the subsoil (Brady 1974). On the average the surface 15 cm of the soil is warmer than the air in every season of the year, while the subsoil is warmer in autumn and winter but cooler in spring and summer due to its protected position and the lag in conduction (Brady 1974).

Differences in soil temperatures between years have been noted by others and can be explained by differences in air temperature, depth of snow cover, aspect, open or sheltered position, altitude, depth to the water table and bulk density (Maclean 1974).

The soil surface at both sites reaches 0°C in November of both years. The 0°C isotherm then moves down into the subsoil and at both sites, all depths are at or below 0°C by March.

III. GROUNDWATER FLOW

1. Beamer Site

Groundwater movement in the 4 m and 8 m piezometers as illustrated in Figure 11 is both upward and downward. (The 6 m piezometer became blocked, so measurements could not be taken.) Recharge occurs during the spring, summer and early fall months when the largest amount of precipitation occurs (Figure 11) and moisture due to thawing is available. Discharge occurs during the late fall and winter months when little precipitation is available to create downward movement of moisture through the soil. Similar trends were found in the Vegreville area by Maclean 1974 and Leskiw 1971.

The hydraulic head in the 4 m piezometer varies between 5.5 and 6.1 m above datum. It ranges between 5.4 and 6.2 m above datum in the 8 m piezometer. Maximum and minimum heights above datum are associated with periods of low or high precipitation, but often occur one or two months after these periods due to a lag time in the piezometers (Maclean 1974).

The water table (Figure 11) ranges between 2.4 m and 1.3 m below the soil surface. It is close to the soil surface and has been noted by others as being important in Solonetz formation (Kovda 1939, Florya and Stoika 1958, Rode 1962, Arshad and Pawluk 1966 and Bowser 1967). The water table is closest to the soil surface during the spring, summer and early fall months due to high precipitation. This occurs during periods of recharge. It is furthest from the surface during the late fall and winter months when little precipitation occurs and groundwater is discharging.

The increase in the height of the water table during times of recharge is due to the addition of moisture from precipitation. The

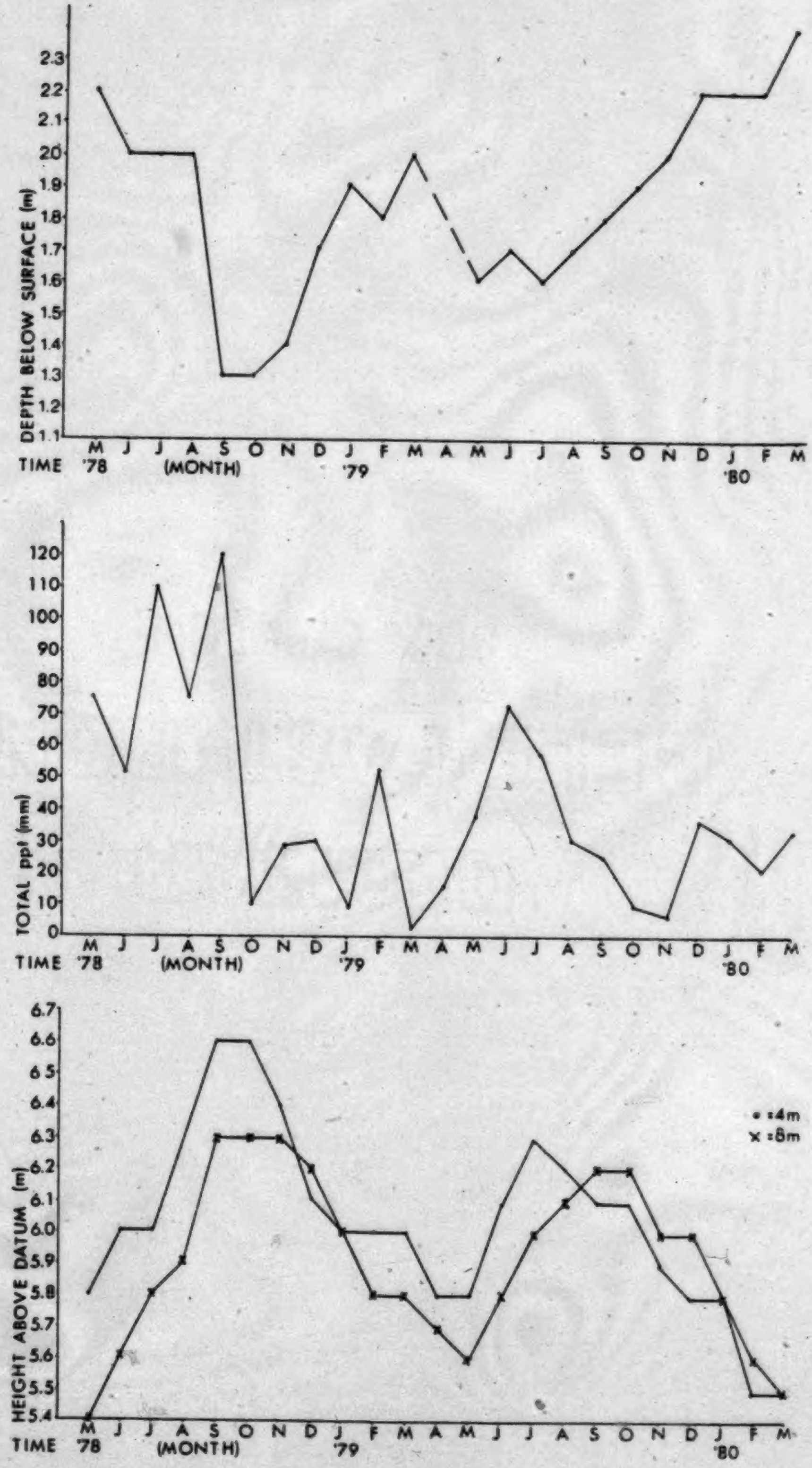


Figure 11: Water table well, precipitation, and piezometer data for the Beamer site. Precipitation data consists of monthly averages from the meteorlogical station at Edmonton Municipal Airport (From Environment Canada 1978-1980).

decrease during times of discharge is due to losses of moisture as water moves upwards toward the soil surface.

Discharging groundwaters do not appear to discharge directly into the pedon being investigated at this site. As a result, any increase in the moisture content in the pedon not resulting from precipitation is brought about by capillary movement. Capillary movement occurs when the total potential at the soil surface is less than the potential at the water table, as water moves from a high to a low matric potential. The hydraulic gradient is upwards and therefore so is the direction of water movement (Baver _et al_. 1972).

The decrease in the elevation of the water table during the winter months is thought to be a result of the upward movement of water towards the soil surface. The soil surface is frozen by November in both 1978 and 1979, and after this month, the water table starts its decline. This lowering of the water table during the winter months has been observed in the literature and can be explained at least in part by the upward migration of moisture from the water table towards the frost zone in response to a temperature gradient (Lebedeff 1927, Cary and Taylor 1962, Willis _et al_. 1964 and Cary _et al_. 1979).

A Black Solonetz predominates at this site. This is in agreement with work done by Maclean (1974). Maclean found Black Solonetz soils in the Vegreville area to occur in areas where groundwater discharged and where the water table was greater than 0.5 m below the soil surface. Groundwater at this site meets both of these requirements.

2. Paulencu Site

No marked downward or upward movement of groundwater occurs at this site (Figure 12). The hydraulic head ranges between 3.4 and 3.9 m above datum in both the 4 m and 6 m piezometers. (The 8 m piezometer was blocked so monitoring could not proceed). The greatest difference in heights above datum for the two piezometers on the same measuring date is 10 cm and this probably is within measurement accuracy. For the majority of the sampling dates, the height above datum is the same for both piezometers. The groundwater movement at this site is termed as being lateral. Lateral flow may exist, as the underlying bedrock is of very low permeability (Le Breton 1963). Toth (1962) found that under extended flat areas groundwater movement could become retarded and slow down. The site location is very flat, and could aid in groundwater retardation and a loss of a flow system. The fact that groundwater is moving into the soil all year round and that the concentrations of soluble salts remain consistent over time, helps support the concept of lateral flow.

The height above datum readings for the piezometers are highest in the spring, summer and early fall months. This is associated with high amounts of precipitation and moisture due to thawing. The readings are lowest in the late fall and winter months and are associated with low amounts of precipitation (Maclean 1974).

The water table (Figure 12) ranges between 2.1 m and 2.6 m below the soil surface. It is closest to the soil surface during periods of high precipitation and thawing (spring, summer and early fall). The water table is farthest away from the soil surface during periods of low precipitation (late fall and winter). These movements of the water table occur at the same time as the maximum and minimum height above

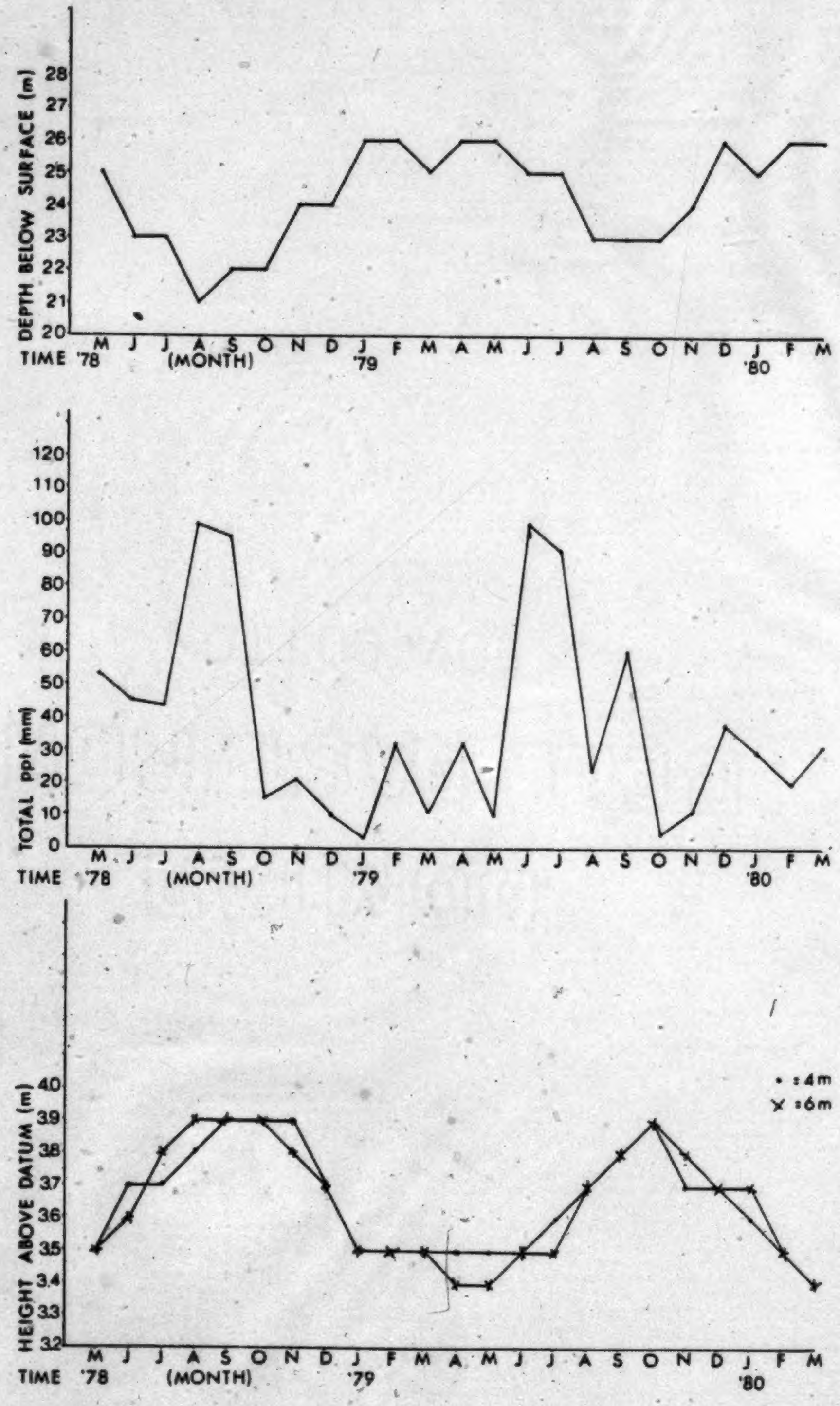


Figure 12: Water table well, precipitation, and piezometer data for the Paulencu site. Precipitation data consists of monthly averages from the meteorlogical station at Vegreville (From Environment Canada 1978-1980).

datum measurements for the piezometers.

Like the Beamer site, the groundwater table appears to remain below the soil pedon and any replenishment or increase in the moisture content in the pedon is a result of upward movement of moisture from the water table by capillarity. Since the water table is lowest during the winter, moisture must be moving in response to a temperature gradient. The soil surface is frozen by November in 1978 and 1979, and after this month, the water table starts its decline. This lowering of the water table during the winter can be explained by the possible upward migration of moisture from the water table towards the frost zone (Lebedeff 1927, Cary and Taylor 1962, Willis et al. 1964 and Cary et al. 1979).

Therefore, moisture is being added to the soil pedon by capillarity and losses occur by evapotranspiration. According to the information from each of the two sites, this seems to be going on throughout the year.

The soil at this site has been classified as a Black Solonetz. In terms of work done by Maclean 1974, groundwater at this site does not fulfill the requirement of having discharging groundwaters but does have a water table that is greater than 0.5 m below the soil surface. Since the water table does not enter into the soil pedon, water is moving upwards into the soil profile by another mechanism. Movement of water from the water table towards the soil surface by capillarity during the winter and summer months, may be one of them.

IV. GROUNDWATER CHEMISTRY

1. Beamer Site

Sodium is the major cation in samples of groundwater collected from the water table well (Table 6). Smaller concentrations of magnesium and calcium are present, and only trace amounts of potassium are detected. The major anion is sulfate and some bicarbonate is present. These groundwater samples have an average pH of 7.5 and an average electrical conductivity (EC) of 8.3 mmhos/cm. Therefore, groundwater at the water table is slightly alkaline and very saline. Work done by Le Breton (1963) describes groundwater in the area as being saline.

The major cation in the 4 m and 8 m piezometers is sodium. Lesser amounts of calcium and magnesium are present, and only trace amounts of potassium are found. Sulfate is the major anion followed by bicarbonate. The pH of groundwater from these piezometers is neutral and the EC saline. Concentrations of all ions except potassium and values for the pH and EC are lowest in the 8 m piezometer.

Similarities existing between groundwater from the water table well and piezometers are that: sodium is the major cation; sulfate is the major anion; the pH ranges around neutral; and the EC is saline. Differences are that: magnesium is the second most abundant cation in samples from the water table well while calcium is the second most abundant in samples from the piezometers; and EC values, pH values and concentrations of all ions except potassium are higher in the water table well.

According to Le Breton (1963) groundwaters at the Beamer site are of bedrock origin as total dissolved salts (TDS) are high and sodium

Table 6: Groundwater chemistry at Beamer and Paulencu sites. *

Instrument	Water Soluble Salts						pH	EC
	Na^+	Ca^{+2}	Mg^{+2}	K^+	HCO_3^-	SO_4^{-2}		
	(me/l)							(mmhos/cm)
Beamer:								
water well	1030	82	189	3	65	1028	7.5	8.2
4m piezometer	450	44	26	2	30	557	7.3	3.9
8m piezometer	405	38	16	4	9	495	6.8	3.7
Paulencu:								
water well	960	85	94	4	42	924	7.3	7.2
4m piezometer	879	70	58	5	23	521	7.2	7.2
6m piezometer	382	32	17	3	18	234	6.9	3.9
8m piezometer**	53	18	3	1	11	52	6.3	0.9

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* Water wells were sampled on July 20, 1979. Piezometers were sampled on May 4, July 20, July 27, August 6, August 10, and August 17, 1979.

** Samples were taken from the 8m piezometer before it became blocked.

predominates as the major cation. Maclean (1974) also found that groundwater discharge of deep origin was to be expected where both TDS and sodium as a proportion of cations were greatest. When the chemistry of the groundwaters is compared to the chemistry of the soil pedon, it becomes obvious that groundwater from considerable depth is moving into the soil. Both the soil pedon and groundwater from the 4 and 8 m piezometers have: sodium sulfate as the major soluble salt; calcium as the second most abundant soluble cation; only trace amounts of potassium; and small amounts of bicarbonate.

2. Paulencu Site

Groundwater samples from the water table well show sodium as the dominant cation. Lower concentrations of magnesium and calcium are also present. Only trace amounts of potassium are evident. Sulfate is the dominant anion, followed by bicarbonate. Values for the pH average around 7.3 and values for the EC around 7.2 mmhos/cm. Groundwater from the water table at this site is similar to that at the Beamer site in that it is slightly alkaline and very saline. The salinity at this site agrees with findings by Le Breton (1963).

The major cations and anions in all three piezometers are similar: sodium is the dominant cation and sulfate the principle anion. Lesser amounts of calcium, magnesium and bicarbonate exist while only trace amounts of potassium are present. The pH ranges from slightly acidic in the 8 m piezometer to slightly alkaline in the 6 and 4 m piezometers. The EC ranges from slightly saline at the 8 m depth to very saline at the 6 and 4 m depths. All values, like those seen at the Beamer site, decrease with increasing depth of the piezometers.

Similarities in all groundwater samples are that: sodium is the dominant cation; sulfate the dominant anion; the pH ranges around neutral and the EC is saline. Differences existing are that: magnesium is the second most abundant cation in samples from the water table well and calcium is the second most abundant cation in the piezometers, and EC values, pH values and concentrations of all ions are higher in the water table well.

According to work done by Le Breton (1963) and Maclean (1974) groundwater at this site is also of bedrock origin. When the chemistry of the groundwaters is compared to the chemistry of the soil pedon, it becomes clear that groundwater from depth is moving into the soil. Increases in salt concentrations towards the upper levels of the saturated zone as well as within the lower pedon, suggest that salts are moving towards the water table through groundwater flow and are being concentrated by losses of water through evapotranspiration. Both the soil pedon and groundwater from the piezometers have: sodium sulfate as the major soluble salt; calcium as the second most abundant soluble cation; only trace amounts of potassium; and small amounts of bicarbonate. Similar trends were recognized at the Beamer site.

V. MOISTURE FLOW ABOVE THE WATER TABLE

1. Beamer Site

In general, the %mc increases from the Bntj2 (15 cm) to the Cs4 horizon (137 cm). There is a large difference in the percentages between the Bntj2 and Bntj3 horizons (Table 7) but the %mc becomes increasingly uniform with depth. This is consistent with work done by Hanks and Ashcroft (1980). Values are low in the top 15 cm of the soil due to vapor losses from the soil which occur by evapotranspiration (Brady 1974).

The Bntj2 horizon has a moisture content which is always below the field capacity and wilting point (Table 7). The %mc is lowest at this depth as the ambient temperature has its greatest effect and losses occur due to evapotranspiration. Factors which create evapotranspiration (ambient temperature, radiant energy, atmospheric vapor pressure, wind, soil moisture supply and density of plants) work mostly at the soil surface so that the moisture content at depth is not greatly effected and losses due to evapotranspiration are much smaller (Brady 1974).

Percent moisture content values in the Bntj3 horizon ranges between the available moisture and wilting point. At this depth the effects of evapotranspiration are less than those within the top 15 cm of the pedon. Losses of moisture occur by evapotranspiration and leaching and additions occur by precipitation and capillarity. As a result of these losses and additions, the %mc values range between the field capacity and wilting point.

Table 7:. Average monthly percent moisture content by volume values using the neutron probe at the Beamer site.

Date	Horizon and Depth (cm)								
	Bntj2	Bntj3	Bsa	Csa	Cs1	Cs2	Cs2	Cs3	Cs4
	15	31	46	70	76	91	107	122	137
May (1978)	33	35	31	32	33	34	35	37	37
June	35	38	34	34	35	36	37	38	38
July	29	34	35	35	36	38	37	39	34
August	29	32	31	33	33	36	36	37	38
September	44	40	34	35	37	37	38	40	40
October	31	35	33	35	36	37	38	41	43
November	28	42	40	40	39	40	39	44	41
January (1979)	17	23	23	21	22	23	23	23	25
February	15	21	19	18	19	20	22	24	25
March	37	42	29	36	35	35	36	36	39
April	38	40	37	35	35	36	36	38	39
May	27	40	38	35	35	37	36	38	39
June	20	35	36	35	35	36	36	39	39
July	26	38	37	35	36	37	36	39	39
August	19	34	37	35	35	37	37	39	39
September	17	30	35	35	35	35	36	39	40
October	14	29	34	34	35	35	35	39	39
November	14	27	31	33	33	35	35	38	38
December	12	25	20	22	25	27	31	33	33
January (1980)	14	22	27	30	33	33	31	35	38
February	36	42	42	42	43	43	43	44	45
March	32	38	38	38	38	39	39	40	40
Average	26	33	33	33	34	35	35	37	38
F.C. (%mc) *	48	44	35	33	37	31	31	42	43
W.P. (%mc) *	28	24	18	16	19	17	17	24	24
A.M. (%mc) *	21	20	17	17	18	14	14	20	19

* Moisture contents were determined on a mass basis and are a result of averaging the appropriate depths.

Between the Bsa and Cs4 horizons, the moisture is in the available moisture range with values approaching field capacity. The soil is kept at this moisture content at depth during times of both discharge and recharge. Due to the nature of the Solonetzic B horizon which limits downward penetration of moisture and the fact that the water table never discharges directly into the pedon, not enough moisture is available to keep the %mc at values approaching field capacity. Therefore, water moving upwards from the water table must be the means by which the pedon is at or near field capacity. This occurs during the spring, summer, fall and winter months.

Water travels upwards into the pedon by capillarity and moves in response to a matric potential. Capillary movement is a result of the attractive force of water for the solids on the walls of the channels through which it moves and the surface tension of water which resists any form except that of a flat plane at the air-liquid interface (Brady 1974). Water moves from regions of high matric potential to low matric potential by capillary movement. Matric potential is a result of adsorption and capillarity. Both of these forces reduce the free energy of the soil water as compared to unadsorbed or pure water, so the potential is always negative. The matric potential affects both soil moisture retention and soil water movement: water moves from high to low potential, or high to low concentrations of water. Water moves during the warm months by capillarity in response to matric potentials. During the cold months, water moves by capillarity from regions of warm to cold in response to differences in matric potential (Cary and Mayland 1972).

By November of both 1978 and 1979, the soil surface at this site is frozen and by March all depths studied are at or below 0^oC. In November of 1978 all depths except the 15 cm depth have the highest moisture content values recorded for the year. Low precipitation and recharging groundwaters are the trends at this time. The water table is moving away from the soil surface. Therefore, the increase in moisture content may be due to water moving upwards from the water table from regions of warm to cold temperatures in response to differences in matric potentials. Moisture contents then decrease in January and February of 1979 at all depths. It is thought that this is due to malfunctioning of the neutron probe and scaler at low temperatures. In March, when all depths are at or below 0^oC, the moisture contents are once again high.

February and March of 1980 have the highest %mc values recorded since November of 1979. Precipitation is low, groundwater is discharging and the water table is at the lowest depth recorded all year. Once again, the high moisture content values seen in the pedon may be due to moisture which moved upwards from the water table.

Moisture movement during the winter in response to a temperature gradient has been reported by others (Taylor 1962 and Cary and Taylor 1962). Cary and Mayland (1972) have the best explanation as to how the water moves. All soil freezes downward from the surface in the fall and is subject to varied thermal gradients throughout the winter. As the soil water freezes, small ice crystals form in the pore spaces. Not all of the water freezes under temperatures commonly experienced in the field. A liquid-like film 10 to 40 A thick remains at the ice-air interface. Liquid forms of varying thicknesses also remain in the soil particle-ice interfaces and in the soil particle-air interfaces.

Since ice crystals freeze out of solution in a pure state, all soluble salts are forced into the unfrozen water films and may form relatively concentrated brines. The vapor pressure of ice is less than that of pure liquid water. Consequently, water will continue to crystallize from the soil solution until the combined osmotic and matric forces reduce the solution's vapor pressure to that of the ice. Under natural conditions in the field, temperature gradients always exist, and liquid water tends to move from warmer to cooler areas. A spontaneous vapor pressure gradient in this same direction is fixed by the temperature of the ice phase. While some movement is in the vapor phase, most of the flow is in the unfrozen liquid films. Since the films may contain high concentrations of soluble salts, it is apparent that salt will also move from warmer to cooler areas in the unsaturated frozen soil (Cary and Mayland 1972).

Most of the liquid phase movement occurs along the water films adsorbed to the soil particles. While there are liquid films in the ice crystal air interfaces, they comprise a small fraction of the total unfrozen water in unsaturated soil because of the relatively small surface area of the ice crystals compared to the soil particles. As the water moves from the warmer to the cooler areas, the ice crystals in the cooler areas grow as the arriving water freezes out. This may continue until the ice crystals completely fill the pore spaces. At this stage, the continuous liquid films along the soil particle surfaces begin to separate as the soil particles are pushed apart by the continued ice crystal growth. This is the beginning of an ice lens that leads to frost heave. Although the water may still move from warmer areas to these large ice lenses, little water can move past them so the lenses continue to grow (Cary and Mayland 1972).

The water in the soil moves mainly in the liquid phase responding to gradients of osmotic, matric, and possibly electrical potentials. The soluble salts are carried by mass flow in the liquid film and some vapor and salt diffusion occurs.

The fact that the %mc values remain fairly constant over time (regardless of the type of groundwater movement, depth of water table or season) leads to the conclusion that water is always being added to the soil to replace any losses. This replacement occurs by precipitation, thawing and capillary movement in the spring, summer and early fall months and by capillary movement from warm to cold regions during the winter months.

2. Paulencu Site

The %mc increases with depth (Table 8) up to the Csa2 horizon then decreases in the IIC2 horizon. There is a large difference in the percentages between the Bntj2 and Bntj3 horizons, but below the difference between depths becomes less significant. The %mc is lowest in the top 15 cm of the soil due to losses by evapotranspiration (Brady 1974).

There is very little change in the %mc values at all depths over the entire 22 month period. The month to month values are much more uniform than those at the Beamer site. Only one period of low moisture contents exists and that is in February of 1979. These values could be a result of the air temperature (-30^{0}C) affecting the neutron probe equipment.

Table 8: Average monthly percent moisture content by volume values using the neutron probe at the Paulencu site.

Date	Horizon and Depth (cm)								
	Bntj2 15	Bntj3 31	Bsa 46	Bsa 70	Csa1 76	Csa2 91	Csa2 107	Csa2 122	IIC2 137
May (1978)	33	42	43	44	44	44	46	40	33
June	43	45	43	44	45	44	46	40	33
July	29	44	45	45	45	45	46	40	33
August	33	44	44	44	45	45	45	38	33
September	47	45	43	44	45	45	46	37	34
October	36	41	41	45	46	46	46	44	36
November	25	46	46	46	48	49	48	49	37
January (1979)	22	46	50	51	52	54	53	54	50
February	4	9	15	15	22	29	35	38	42
March	38	45	44	43	44	43	35	40	-
April	40	45	44	44	44	45	45	47	-
May	31	40	46	45	44	45	45	48	-
June	21	42	45	44	44	46	45	47	37
July	22	40	45	45	44	46	45	48	47
August	16	31	42	44	45	46	45	47	37
September	15	35	41	43	45	45	45	47	35
October	14	32	40	43	45	46	45	47	35
November	14	30	38	41	42	45	44	44	35
December	14	22	35	38	40	42	42	44	33
January (1980)	15	33	38	40	42	42	42	44	35
February	37	43	45	45	46	47	47	45	42
March	30	37	39	39	40	40	41	38	-
Average	26	38	42	42	42	44	44	44	35
F.C. (%mc) *	47	53	54	54	59	56	56	56	35
W.P. (%mc) *	30	24	28	28	35	32	32	32	15
A.M. (%mc) *	18	29	26	26	24	24	24	24	20

* Moisture contents were determined on a mass basis and are a result of averaging the appropriate depths.

The Bntj2 horizon has a moisture content which is below the field capacity and wilting point. The %mc is lowest at this depth as the ambient temperature has its greatest effect and losses occur by evapotranspiration (Brady 1974).

Moisture is in the available range throughout the rest of the soil pedon with values very close to field capacity. The moisture content is in this range since any losses resulting from the effects of evapotranspiration are balanced by additions through capillary rise along a matric potential gradient. The effects of evapotranspiration are also very small at depth in the soil pedon.

Moisture contents are highest at all depths in November 1978, January 1979 and February and March of 1980. In January of 1979, moisture contents are near field capacity. Groundwater moves laterally at this site so groundwater does not discharge directly into the soil pedon. The water table is at the lowest point recorded during the study period during these times of high moisture contents. The addition of moisture through precipitation is also low. Therefore, the moisture content of the soil may be increasing by the addition of water from the water table. Since the highest %mc values are occurring during the winter months, it is possible that the increase in moisture is due to capillary movement upwards from the water table towards the frozen soil surface from regions of warm to cold temperatures. This type of moisture movement has been reported in the literature and a discussion of how the moisture moves is described in the previous section.

The fact that the %mc remains so consistent over time (regardless of the type of groundwater movement, depth of water table or season) leads to the conclusion that an equilibrium condition exists where losses of moisture equal additions of moisture. This same trend was observed at the Beamer site. Replacement of soil moisture occurs by precipitation, thawing, and capillary movement in the spring, summer and early fall and upward movement of water from the water table in response to a temperature gradient in the late fall and winter months.

VI: SALT MOVEMENT ABOVE THE WATER TABLE

1. Beamer Site

The salinity (soil solution conductivity) increases with depth up to 76 cm and then decreases (Figure 13). Average values for each depth from 31 to 91 cm are 42, 89, 98, 105 and 91 mmhos/cm. The salinity of the soil solution varies the most at the 31 cm depth and this variability decreases with depth.

Lowest salinity readings occur from January to March and highest from November to December. Maximum and minimum values exist, but month to month differences between values are not large.

The highest EC values are found in the Bsa and Csa horizons. Excess salts have been leached out of higher horizons and salts have been moved upwards and deposited from lower horizons in these horizons of salt accumulation.

The salinity of this pedon is related to the moisture flow above the water table. As was discussed in the last section, the moisture content of the soil pedon like the salinity: increases down the pedon; has lowest values at the soil surface; is most variable near the soil surface; and has values that are in general, consistent over time. The rise and fall of the soil solution conductivities generally follow the increases and decreases of soil moisture at each depth. The high salinity values at each depth in November of 1979 correlate well with the highest moisture content values recorded for the year. Low values recorded in January and February of 1979, also agree with low moisture contents. These low values are thought to be a result of the salts precipitating out at low temperatures, as well as problems with the

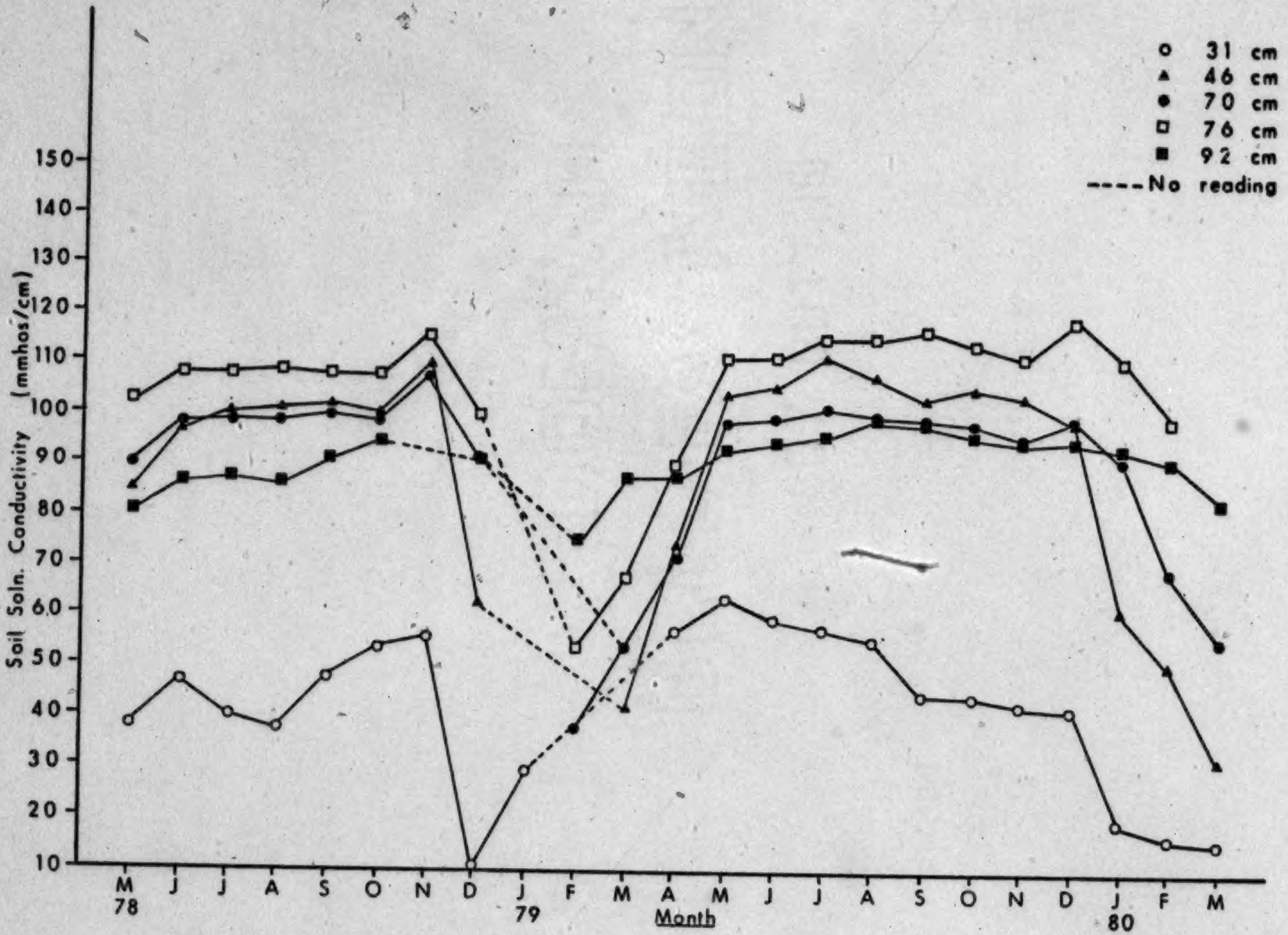

Figure 13: Soil solution conductivity values at the Beamer site.

salinity bridge. Low salinity levels are also present in February and March of 1980, when moisture contents are once again high. These low salt levels are thought to be a result of the reasons previously mentioned.

Therefore, a relationship exists between the soil moisture content and the soil salinity. When moisture moves upwards from the water table soluble salts dissolved in groundwater are deposited in pore spaces. Both moisture and salts are concentrated at depth, as water leaving through evapotranspiration is balanced by the upward flow along a matric potential gradient. The uniformity of the %mc and EC values over time, result in the conclusion that both are being added to the soil throughout the year. Salts are added to the soil by moisture movement in the form of capillarity in the spring, summer and early fall months and upward movement from the water table towards a freezing zone in the winter.

Table 9 illustrates the types of soluble salts that are being brought upwards into the soil profile by groundwater. The principal salt in the Ah, Ahe and top of the Bntj1 horizons of the soil pedon is sodium bicarbonate. Low concentrations of calcium, magnesium, sulfate and potassium are also present within these horizons. The pH is acidic and the EC non-saline.

Within the lower Bntj1 and upper Bntj2 horizons, both sodium bicarbonate and sodium sulfate are present: sodium bicarbonate in higher concentrations than sodium sulfate. Calcium, magnesium, and potassium concentrations have not changed, while sodium concentrations have increased. The pH is acidic and the EC non-saline.

In the lower Bntj2 and upper Bntj3 horizons, sodium concentrations have once again increased, while concentrations of the other cations

Table 9: Average soluble salt concentrations over a ten month period at the Beamer site.

Analysis	Horizon and Depth (cm)							
	Ah - Bntj1	Bntj1 - Bntj2	Bntj2 - Bntj3	Bntj3	Bsa	Csa	Csl	Csl
	0 - 10	10 - 20	20 - 31	31 - 41	41 - 51	51 - 61	61 - 71	71 - 81
Water Soluble Salts (me/100 gm)								
Na^+	3.5	4.8	6.7	10.1	11.5	11.8	13.0	12.9
Ca^{+2}	0.7	0.4	0.5	12.7	13.6	14.4	15.4	15.2
Mg^{+2}	0.6	1.0	1.0	3.3	4.3	4.0	4.6	4.2
K^+	0.2	0.1	0.1	0.2	0.2	0.2	0.2	0.2
HCO_3^-	1.2	1.6	2.6	1.9	1.2	0.9	0.9	0.8
$SO_4^{=2}$	0.6	1.0	2.4	26.4	32.2	31.4	34.4	33.7
pH	5.1	6.1	7.3	7.7	7.8	7.9	7.9	7.9
Electrical Conductivity (mmhos/cm)	0.5	0.5	0.7	1.8	2.2	2.2	2.4	2.3

have remained the same. Both sodium bicarbonate and sodium sulfate concentrations are the same. The pH is neutral and the EC non-saline.

Calcium and magnesium concentrations increase in the lower B3 horizon: calcium increasing more than magnesium. There are now slightly higher concentrations of calcium than sodium. Sulfate concentrations have increased to the extent that salts present are mainly sulfate salts. The pH is basic.

In the Bsa, Csa, Cs1 and Cs2 horizons, concentrations of all ions except potassium and bicarbonate have increased. Calcium is the major cation and sulfate the major anion: therefore the principal soluble salt is calcium sulfate. The pH is basic and the EC non-saline.

In general, changes which occur with increasing depth in the pedon are that: all cation concentrations increase except potassium; calcium and magnesium concentrations increase after 30 cm at a much faster rate than sodium; pH changes from acidic to alkaline; and the concentration of bicarbonate decreases while sulfate increases.

The Solonetzic B horizons are situated within the top 40 cm of the pedon at this site. Within the top 40 cm the highest sodium to calcium and magnesium ratios in the pedon exist. An average ratio is 3.5 to 1. Therefore, sodium predominates within the Solonetzic B horizons of this Black Solonetz. The principle salt within the top 20 cm is sodium bicarbonate with smaller amounts of sodium sulfate present. From 20 cm to 40 cm, the major salt is sodium sulfate. Therefore, both of these salts are responsible for the development of the B horizon of Solonetzic soils. Sodium bicarbonate is found in the Bntj1 and Bntj2 horizons, which are high up in the profile. Sodium sulfate is not as soluble and therefore transmittable as sodium bicarbonate so it is found lower down in the solonetzic horizons. Sodium sulfate concentrations increase with depth in the pedon. Concentrations are especially high in horizons of salt accumulation where calcium and magnesium sulfates have precipitated out.

Samples of groundwater from the Beamer site have sodium followed by calcium and magnesium as the major cations. Only trace amounts of potassium are present. Sulfate is the major cation followed by bicarbonate. The pH is alkaline and the EC very saline. Therefore, salts found in the pedon at this site are very similar to those found in groundwater samples. When groundwater moves upwards into the soil profile, it brings with it soluble salts, which are introduced and deposited in the soil pedon.

2. Paulencu Site

As with the Beamer site, the salinity of the soil solution increases from the 31 to the 76 cm depth and then decreases (Figure 14). Average values for each depth monitored are: 76, 95, 98, 131 and 122 mmhos/cm. The salinity of the soil solution varies the most at the 31 cm depth and this variability decreases with depth. This is a result of the effects of evapotranspiration.

Lowest salinity values occur from January to March. Throughout the rest of the year, values remain fairly constant.

The highest electrical conductivities are in the horizons of salt accumulation: Bsa, Csa1 and Csa2 horizons. Salts are leached down from above and are deposited at this depth from the upward movement of groundwater from the water table, creating high electrical conductivities and an accumulation of salts.

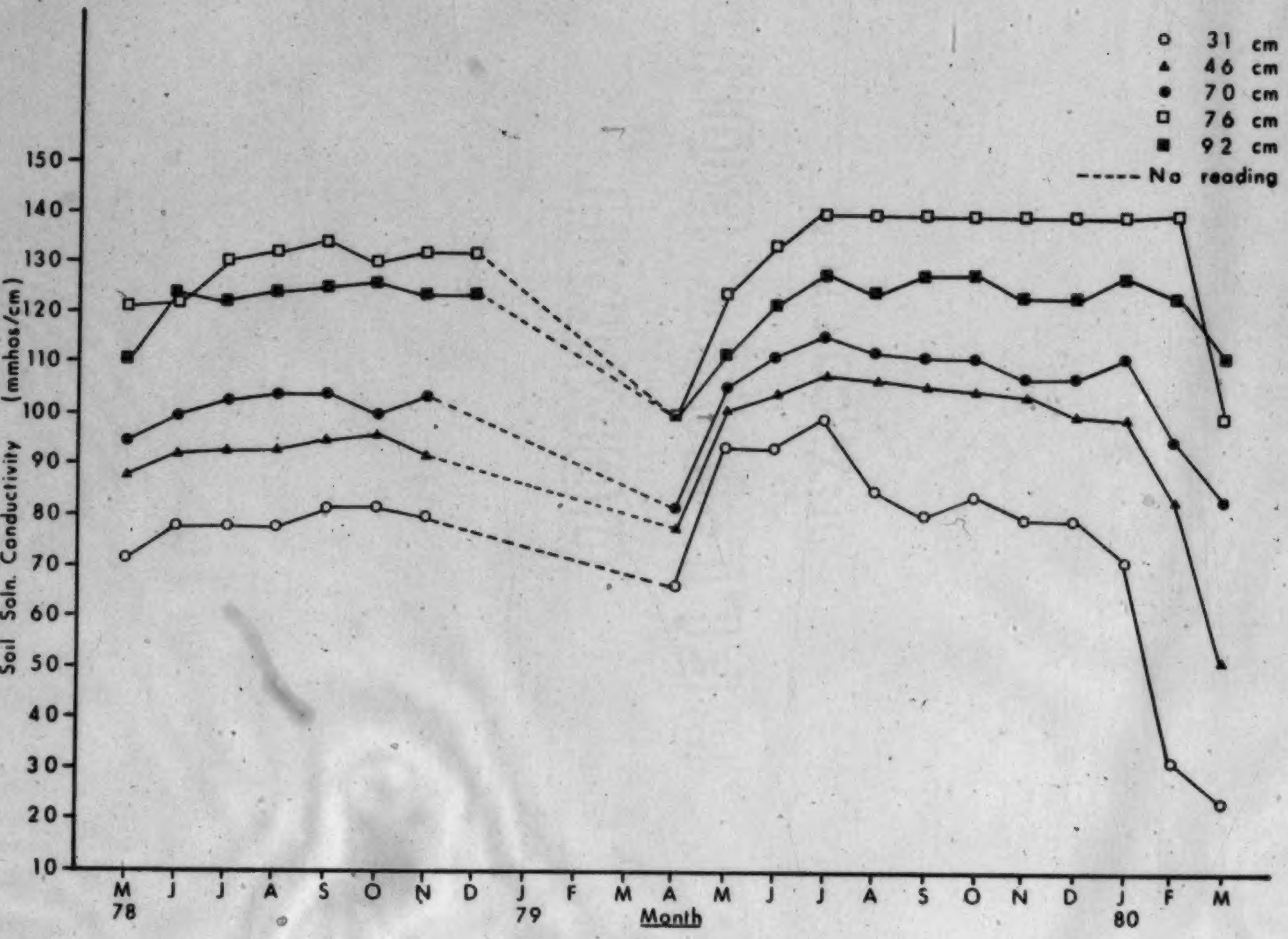

Figure 14: Soil solution conductivity values at the Paulencu site.

The salinity of this pedon, like that at the Beamer site, is related to soil moisture. Both the moisture contents and soil solution conductivities: increase down the profile; have lowest values at the soil surface; are most variable near the soil surface; and have values that are in general, consistent over time. The rise and fall of the soil solution conductivities generally follow the increases and decreases of soil moisture at each depth. The soil solution conductivity values like the %mc values, are very consistent over time. The highest moisture content values in November 1978, January 1979, February 1980 and March 1980 are not mirrored in the salinity values. This may be a result of the soil temperatures (which are below freezing) affecting the soil salinity bridge, or causing the salts to precipitate out.

Therefore, a relationship exists between the soil moisture content and the soil salinity. This relationship has been discussed for the Beamer site.

Table 10 shows the types of salts found in the soil pedon. In the Bntj1horizon, sodium is the major cation followed by calcium and magnesium. Only trace amounts of potassium are present. Both bicarbonate and sulfate are present: sulfate being present in slightly higher concentrations than bicarbonate. The pH is acidic and the EC non-saline.

With increasing depth in the soil pedon, moving from the Bntj1 to the Bntj3 horizon, concentrations of all ions except potassium increase. Sodium is still the major cation and sulfate the major anion. The pH remains acidic and the EC non-saline. Within these horizons, both sodium sulfate and sodium bicarbonate are the principal salts.

Throughout the rest of the soil pedon, all ion concentrations

Table 10: Average soluble salt concentrations over a ten month period at the Paulencu site.

Analysis	Horizon and Depth (cm)							
	Ah - Bntj1	Bntj2	Bntj3	Bntj3 - Bsa	Bsa	Bsa	Csal	Csal
	0 - 10	10 - 20	20 - 31	31 - 41	41 - 51	51 - 61	61 - 71	71 - 81
Water Soluble Salts (me/100 gm)								
Na^+	4.9	6.6	7.2	12.0	14.5	17.2	18.0	19.8
Ca^{+2}	1.4	1.2	1.8	9.0	11.7	13.0	13.7	13.7
Mg^{+2}	0.9	1.3	1.6	3.6	4.8	5.5	6.6	5.6
K^+	0.2	0.1	0.1	0.2	0.2	0.2	0.2	0.3
HCO_3^-	0.8	1.1	1.3	1.0	1.1	0.9	1.0	0.8
SO_4^{-2}	1.7	2.5	2.4	28.0	34.0	41.0	43.0	43.3
pH	5.1	6.0	6.8	7.1	7.5	7.6	7.7	7.7
Electrical Conductivity (mmhos/cm)	0.7	0.8	0.9	1.8	2.3	2.6	3.1	2.8

increase except potassium and bicarbonate. Both of these ion concentrations remain the same. Sodium is the major cation and sulfate the major anion: therefore the principal salt is sodium sulfate. The pH is alkaline and the EC is at the low-salinity level.

In general, with increasing depth in the soil pedon at the Paulencu site: all cation and anion concentrations increase except potassium; sulfate increases much more than bicarbonate which tends to level off; sodium is the predominate cation; pH values change from acidic to alkaline; and the EC changes from non-saline to levels of low-salinity.

The Bntj horizons are within the top 43 cm of this pedon. The highest sodium to calcium and magensium ratios occur in the top 40 cm showing that sodium is the major cation. The average ratio is 2.3 : 1. This shows that sodium is the predominant cation in the Solonetzic B horizons. Up to the 30 cm depth, both sodium bicarbonate and sodium sulfate are responsible for Solonetz formation. Below this depth, sodium sulfate is the major salt.

Samples of groundwater from the Paulencu site result in the same trends as was seen at the Beamer site. Therefore, salts present in the groundwater are similar to those found in the soil. The conclusion is therefore that groundwater is responsible for the addition of soluble salts into the soil pedon.

VII. RESULTS OF THE DYE APPLICATIONS

Two separate dyes have been used in this study to monitor the movement of water. Orange G was placed in the 8 m piezometers at both sites to determine if water at depth was moving upwards. Uranine was applied to the soil surface at two different locations at each site to see if there was any downward movement of water away from the soil surface.

At the Beamer site, Orange G was applied on July 20, 1979 and appeared in the water table well on September 7, 1979. The dye was applied to the Paulencu site at the same time, but was not detected in the water table well. The dye appeared in the 6 m piezometer on April 28, 1980. The results of this dye application, illustrates that groundwater at depth does move upwards towards the soil surface at both the Beamer and Paulencu sites. Groundwater moves faster at the Beamer site as compared to the Paulencu site. This reflects the nature of the parent material.

Uranine was applied to the soil surface at two different areas at each of the sites on July 15, 1979. Four soil samples were collected from each area using an Oakfield Soil Sampler on September 7, 1979. The samples were studied for traces of the dye in the laboratory, using an untraviolet light. Results of the Uranine application show that the dye moved through the Ah and Ahe horizons but only penetrated 2.5 cm into the Bntj horizons. The dye moved down around the soil columns into the B horizon, but did not move through the pedon. These same results were observed from soil columns set up in the laboratory. Therefore, when water moves downwards, it is not able to penetrate the hard, impermeable Solonetzic B horizon. Water, after it has moved down through the Ah and Ahe horizons, either remains perched and flows on top of the B horizon, or flows down around the hard, compact columns in this horizon.

Results of the dye applications can be used to help explain water movement at the Beamer and Paulencu sites. Water does not move downwards into the B horizon, but enters this horizon by moving upwards from depth. Groundwater enters the pedons by moving upwards from the water table. The velocity of the dye movement explains why only lateral movement is detected at the Paulencu site. The parent material may be so impermeable that any discharge or recharge may take a very long time to be detected. Water moves at a faster rate at the Beamer site and movement is more easily detected.

Therefore, the major type of water movement at the sites of interest in this study is that of upward flow towards the soil surface. Groundwater flows upwards, and enters the soil pedon by capillary movement from the water table. Movement is much slower at the Paulencu site than the Beamer site, and is possibly a result of the nature of the parent material.

VIII. THE RELATIONSHIP OF SOLONETZ SOILS TO SALTS, WATER AND SEASON

Up to this point the results of various chemical and physical techniques used in this study have been presented. What is of interest now is to establish the role of seasonal salt and water fluxes in the genesis of Solonetzic B horizons.

1. Role of Water

The primary factor in the formation and occurrence of sodic soils, is the accumulation of sodium ions in the solid and/or liquid phase of the soil. As a result, soil water plays a decisive role in the development of these soils. In salinization and desalinization processes, soluble salts are transported by water. Consequently, as a result of solid-liquid interface phenomena, the chemical characteristics of the soil solution governs the exchangeable ion composition of the soil adsorption complex and therefore the properties of the soil.

At the two sites studied in this thesis, groundwater is the means by which salts are added to and removed from the soil. At both sites the water table is close to the soil surface (2m) therefore fulfilling one of the prerequisites discussed in the literature as being necessary for Solonetz formation (Rode 1962, Maclean 1974, Szabolcs and Kovda 1979). Groundwater movement is lateral (Paulencu site), downward and upward (Beamer site). Groundwater discharge is usually the water movement described when the genesis of Solonetzic soils is discussed. Toogood and Cairns (1978) stated that within the northern Great Plains region of Canada, salts were brought to the soil surface through groundwater discharge. Maclean and Pawluk (1975) found Black Solonetz soils to predominate where discharge occurred and the water table was at least 0.5 m beneath the soil surface. At the Beamer and Paulencu sites, the type of groundwater movement as well as the shallow water table are important. Discharging and laterally moving groundwaters are the means by which salts are brought to the water table, but groundwater from the water table does not appear to move directly into the soil pedon. Capillary movement is responsible for the addition of moisture into the soil. Capillary movement is also the probable way by which soluble salts are introduced into the pedon. Other authors have found capillary movement to be important in Solonetz formation. Szabolcs and Kovda (1979) found Solonetz soils to form where the soil profile was capillarily linked with mineralized groundwater. The presence of a high water table when the groundwater is of a high soluble salt content leads to the translocation of salts throughout the soil profile by capillary action (Edgalby and Naguid 1965). The addition of sulfates and bicarbonates of calcium, magnesium, sodium and potassium was observed at the study areas.

The chemistry throughout the soil pedons is similar to that of the groundwaters: sodium sulfate is the major soluble salt; calcium is the second most abundant soluble cation; trace amounts of potassium are present; and low concentrations of bicarbonate exist. Therefore, groundwater from the water table directly relates to the chemistry of the soil. In many cases, water soluble salts responsible for the alkalinity or salinity of soils are accumulated from the groundwater (Szabolcs and Kovda 1979). Capillary movement results in the addition of both salts and moisture to the soil pedon and values for the %mc by volume and EC show a relationship between these two variables.

Both factors increase with depth in the pedon, are most variable near the soil surface, are fairly consistent over time and follow the same annual trends. Thus, the %mc by volume and EC values are related.

The role played by groundwater in the genesis of the Solonetzic B horizon is the upward movement from the water table by capillarity into the soil pedon, depositing both soluble salts and moisture. These salts are brought upwards into the soil pedon and concentrate by evaporation in the spring and summer (Szabolcs and Kovda 1979) and crystallization at the freezing zone in the late fall and winter (Cary and Taylor 1979). The fluctuation of the water table determines the upward and downward migration of the salt solutions, which is one of the most important conditions for Solonetz formation (Szabolcs and Kovda 1979). At the Beamer and Paulencu sites, the water table rises in the spring, summer and early fall months. This is a result of the downward movement of water from the soil surface due to snow melt and precipitation. In the late fall and winter, the water table declines. An increase in moisture and salt concentrations throughout the soil profiles occurs during this period. It is possible that upward moisture movements into the frost zone, which are probably largely in the liquid phase (Jumikis 1962, Cary 1965, Hoekstra 1964, Maclean 1974) could be a mechanism for transfer of salts. Therefore salt migration occurs at these sites. Salts are leached downwards during wet periods in the spring, summer and early fall and are brought upwards in the summer and winter months by capillary movement. This mechanism of migration has been noted by others (Rode 1962, Maclean 1974).

The upward and downward flux of water creates very different soil conditions. When groundwater moves upward, it carries with it dissolved soluble salts. When these salts are present in the upper B horizon, the soil is flocculated and generally there are no adverse physical conditions created. When there is downward leaching by rain water or spring melt, excess salts become leached from the pore spaces, and if sodium ions dominate deflocculation results. The salts are now in concentrations which create adverse physical conditions in the soil through solonetzization (Bentley and Rost 1947). The end result is the creation of a Solonetz. The formation of this soil is accompanied by dispersion, peptization of soil colloids which reduces drainage, hydrolysis of sodium creating an alkaline reaction and the formation of a dense, compact, highly colloidal, more or less impermeable B horizon (Bentley and Rost 1947).

2. Role of Salts

The solubility of salts accumulated in soils plays an important role in the formation of sodic soils. Salts accumulate in reverse sequence of their solubility, and salt accumulation develops if the leaching of salts becomes restricted and/or the soil layer is connected with salt sources (such as mineralized groundwater, irrigation water, etc.) (Szabolcs and Kovda 1979). When salt accumulation prevails over leaching, the absolute and relative quantities of salts with higher solubility increase. If leaching is the dominant process, the readily soluble salts will accumulate in the drainage water and the less soluble salts in the soil. This results in the vertical distribution of salts and changes in the ionic composition of the salts along the soil profile reflect the dominating process (leaching or accumulation) in the soil (Szabolcs and Kovda 1979).

At the sites of interest to this study two salts predominate on top of the Bntjl horizons where solonetzization or solonization occurs. Sodium bicarbonate with lower concentrations of sodium sulfate are found at the Beamer site while sodium sulfate and lower concentrations of sodium bicarbonate are found at the Paulencu site. With increasing depth in both pedons, concentrations of all soluble sulfate salts increase. From the types and concentrations of the various types of salts present, it becomes obvious that water movement is dominantly upwards. The most soluble salt (sodium bicarbonate) is in the top 31 cm of the soil, while the least soluble (calcium and magnesium sulfates) increase with depth below 31 cm. Sodium sulfate is also quite soluble and is found within the top 31 cm of the pedons.

The accumulation of salts, especially sodium salts at the Beamer and Paulencu sites is a result of the upward movement of groundwater from the water table. This type of salinization is acknowledged as being a primary way in which soils accumulate salts (Gedroyts 1912, Rode 1962, Szabolcs and Kovda 1979). Desalinization is a result of leaching, and these sites are leached by precipitation and snow melt. During desalinization, the groundwater periodically adds new amounts of sodium salts by capillary rise through the soil stratum followed by evaporation during the warm seasons or deposition on freezing during the cold seasons. As a result of the alternating salinating and desalinating processes, the content of exchangeable sodium reaches figures sufficient to ensure solonization. This process is characterized by considerable participation of exchange sodium in the soil-forming process. If such a regime lasts long enough, the amount of sodium may reach figures sufficient to ensure the transformation of the soil into a Solonetz (Rode 1962).

At the Paulencu and Beamer sites, such salinization and desalinization occurs throughout the year. These processes have resulted in the soils being classified as a Solonetz.

Solonization occurs near the soil surface on the top of the B horizons. When sodium occurs as sodium bicarbonate, it is readily adsorbed onto the soil colloids by displacing adsorbed calcium and magnesium. This reaction is intense and the sodium displaces almost all of the exchangeable calcium and magnesium. When sodium occurs as sodium sulfate, sodium replaces adsorbed calcium and magnesium ions but the reaction is not as intense, and soluble instead of insoluble products are formed. Therefore, only some calcium and magnesium ions are replaced (Rode 1962). With leaching, the products of these reactions are transmitted into lower horizons, where they accumulate and form layers of salt accumulation. Once a certain percentage of exchangeable sodium exists, the ion exerts a considerable action on soil properties (Rode 1962). In the literature ESP values between 12 to 15% are cited as being the requirements for dispersion and the development of Solonetzic properties (de Sigmond 1938, Gedroyts 1912). The ESP is 24% at the Beamer site and 27% at the Paulencu site. These values are much higher than those cited in the literature as minimal for solonization.

Solonization results in the dispersion of soil colloids and the hydrolysis of sodium bicarbonate. An alkaline reaction results. As a result of the dispersion and alkalinity, some of the peptized colloids in the form of a suspension are leached from the upper horizons into lower horizons. Other colloids undergo decomposition by the action of microbes, water, carbonic acid and other agents (Rode 1962). This is facilitated by the peptized state of the colloids in which water is able to act from all sides on all the finest particles. The decomposition products are also leached into the underlying horizons. Due to the alkaline reaction, silicic acid is easily able to form soluble silicates of alkali, mainly of sodium. As a result of this, the soil colloids are leached out of the upper horizons to form a horizon of illuviation called the Solonetzic Bnt horizon. It is characterized by being hard when dry and swelling to a sticky mass of low permeability when wet. Typically this horizon has prismatic or columnar macrostructure that breaks to hard to extremely hard blocky peds with dark coatings.

3. Role of Season

Each of the four seasons exerts an influence on the genesis of the Solonetzic B horizon at the Beamer and Paulencu sites. During the spring, summer and early fall months, snow melt and precipitation create recharging conditions through the unsaturated zone which act to leach downwards through the soil putting salts into solution and removing excess soluble salts. Maclean (1974) found these two processes to result in recharge in the Vegreville area. Throughout the same period, temperatures rise and result in evaporating conditions. Evaporation causes an increase in the concentration of salts in groundwater and soil solutions accompanied by an enrichment in calcium and magnesium carbonates and gypsum (Shavrygin 1960). Apart from the precipitation of non-readily soluble salts into the solid phase, inter-reactions between the adsorption complex of the soil and the soil solution occurs. Exchange reactions include the displacement of calcium and magnesium by sodium or the reverse (Shavrygin 1960). Evaporation has been discussed in the literature as the major means by which salts become concentrated and deposited in Solonetz soils (Dalin and Zheng-quan 1979, Hassan and Gharbeh 1977, Toogood and Cairns 1978).

During the late fall and winter months, temperatures drop and the soil starts to freeze. During this time at both sites, decreases were observed in the height of the water table along with increases in the moisture content of the soil. From these two variables, it is proposed that water is moving upwards from the water table towards the freezing zone, carrying with it soluble salts. This mechanism of water movement has been recognized by others (Ferguson _et al_. 1964, Benz _et al_. 1968, Cary and Mayland 1972, Cary _et al_. 1979).

As a result of the above, it is proposed that Solonetz development occurs throughout the entire year. Salts are brought upwards into the soil during both the winter and summer months and are leached out of the soil in the early fall, spring and summer months. This alternating salinization and desalinization ultimately results in conditions leading to solonization and the development of a Solonetz. The pedons at the Paulencu and Beamer sites are being kept at the Solonetz stage of development by these continuing processes.

SUMMARY AND CONCLUSIONS

The purpose of this research is to further the knowledge on the genesis of Solonetzic soils in the Province of Alberta. This study deals specifically with an evaluation of the salt and water fluxes into Solonetz soils at two sites in East-Central Alberta. Both sites have soils classified in the Solonetzic Order of soils, and the soil pedons investigated in this study are those from the Black Solonetz Subgroup. Solonetzic soils at site one (Beamer site) have developed from lacustrine parent material while the pedons at site two (Paulencu site) have developed from weathered residual Edmonton formation.

In order to identify the processes likely responsible for the development of the B horizon of Solonetzic soils, the following field and laboratory investigations were undertaken. Field work involved: weekly sampling in 10 cm increments from the soil surface down to a depth of 81 cm; collecting groundwater samples from water table wells and piezometers; measuring the depth to groundwater in water table wells and piezometers; measuring soil solution conductivity using salt cells; collecting horizon samples from each profile; taking depth-moisture readings using a neutron probe; and taking soil-temperature readings from 0 to 183 cm. This field work was done throughout the entire year in order to determine seasonal variabilities. Dyes were also added to the soil surface and deepest piezometers in order to measure both upward and downward movement of water through the soil.

Laboratory investigations involved measuring the soluble salts, pH, EC, and %mc in the weekly soil samples as well as in the groundwater samples. The soil profiles at each of the two sites were characterized by conducting the following physical and chemical analyses on each of the horizons, soluble salts; cation exchange capacity and exchangeable cations; pH; exchange acidity; percent organic matter; total nitrogen; calcium carbonate percentage; field capacity and wilting point; and particle size analysis.

The results of this research are best summarized by answering the four questions listed in the introduction to this thesis. The questions and answers are listed below:

1. Q: To determine the movement of moisture within the soil profile.

   A: The predominant mode of moisture movement is by capillarity. Groundwater moves upwards from the water table towards the soil surface by capillary movement. This type of moisture movement occurs along with both lateral and downward movement of water. Moisture moves laterally on top of the B horizon when it is wet and therefore dispersed and impermeable. When this horizon is dry water is able to move downwards between the cracks in the soil columns, therefore creating a leaching of the soil.

2. Q: To determine the amounts, types, and movement of salts responsible for the formation of the Solonetzic B horizon.

   A: Solonetzization occurs on top of the B horizon. The salts present within this area and responsible for Solonetz formation are sodium bicarbonate and sodium sulfate. These salts are very soluble and are easily transmitted upwards towards the soil surface by upward moving groundwater. Capillary movement of groundwater along with evaporation and crystallization results in the accumulation of and concentration of salts in the soil pedons. Leaching by precipitation and snow melt results in the removal of excess soluble salts. The alternation of these two processes results in the sodium ion becoming adsorbed onto soil colloids in amounts leading to the process of solonization and the physical and chemical characteristics associated with Solonetz soils. The ESP is greater than the 12 to 15% cited in the literature, within the top of the Bntjl horizon. The ESP is 24% at the Beamer site and 27% at the Paulencu site. Sodium occurs within this horizon in a ratio of soluble sodium to soluble calcium and magnesium of 2.4:1.

3. Q: To determine the relationship between the salts present and the moisture profile.

A: Salts are brought upwards from the water table by capillary movement and are concentrated by evaporation or freezing conditions. Salts are leached downwards during times of snow melt and precipitation. These variables are closely related within the soil pedon as both are most variable near the soil surface, increase down the pedon, are fairly consistent over time and follow the same general annual trends.

4. Q: To determine the role of season in the genesis of Solonetzic soils.

A: The genesis of Solonetzic soils occurs throughout the entire year. Salt accumulation occurs in the spring and summer months when salts are brought upwards by capillarity and concentrate by evaporation. Accumulation also seems to occur in the winter when water moves upwards from the water table towards the freezing zone, depositing salts upon freezing. Salts are leached out during the spring, summer and early fall by snow melt and precipitation. Therefore, alternating salinization and desalinization results in enough sodium being adsorbed onto the soil colloids to bring about the chemical and physical properties associated with Solonetz soils.

This thesis has developed a theory as to the genesis of Solonetz soils in East-Central Alberta by supporting some already existing ideas as well as generating some new ones. More research is needed in this area of science so it will become easier to develop techniques for the reclamation of these soils.

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APPENDICES

Appendix 1: Weekly soil temperatures in ^{o}C at Beamer site.

DEPTH (cm)	TEMPERATURE (^{o}C) - 1978					
	MAY 2	MAY 10	MAY 17	MAY 24	MAY 31	JUN 7
0	12.2	11.1	12.8	12.2	11.1	20.0
2.5	11.7	11.1	12.2	13.3	11.1	18.9
5	11.1	11.1	11.1	13.3	10.6	17.8
7.5	10.6	10.6	11.1	13.3	10.6	17.8
10	10.6	11.1	10.6	13.3	10.6	17.2
12.5	10.0	10.0	10.0	13.3	10.0	16.7
15	9.4	10.0	10.0	13.3	10.0	16.1
17.5	8.9	10.0	10.0	13.3	10.0	16.1
20	9.4	10.6	10.0	13.3	10.0	16.1
22.5	9.4	10.6	10.0	13.3	10.0	16.1
25	9.4	10.0	10.0	13.3	10.0	16.1
27.5	8.9	10.0	10.0	13.3	10.0	15.6
30	8.3	10.0	10.0	13.3	10.0	15.6
32.5	8.3	9.4	10.0	12.8	10.0	15.6
35	7.8	8.9	9.4	12.2	10.0	15.0
37.5	7.8	8.9	9.4	12.2	10.0	15.0
40	7.8	9.4	9.4	12.2	10.0	15.0
42.5	7.2	8.9	8.9	12.2	10.0	14.4
45	7.2	8.9	8.9	12.2	10.0	14.4
47.5	7.2	8.3	8.9	11.7	10.0	13.9
50	6.7	8.3	8.9	11.1	9.4	13.3
52.5	6.7	7.8	8.3	11.1	9.4	13.3
55	6.7	8.3	8.3	11.1	9.4	13.3
57.5	6.7	7.8	8.3	11.1	9.4	12.8
60	6.1	7.8	8.3	10.6	9.4	12.8
62.5	6.7	7.8	8.3	10.6	10.0	12.8
65	6.1	7.8	7.8	10.0	9.4	12.2
67.5	6.1	7.8	7.8	10.0	9.4	12.2
70	5.6	7.2	7.8	10.0	8.9	11.7
72.5	5.6	6.7	7.8	9.4	8.9	11.7
75	5.0	6.7	7.2	8.9	8.9	11.1
77.5	5.0	6.7	7.2	8.9	8.9	11.1
80	5.0	6.7	7.8	8.9	8.9	11.1
82.5	5.0	6.7	7.2	8.9	8.9	11.1
85	4.4	6.7	7.2	8.9	8.9	10.6
87.5	4.4	6.7	9.4	8.9	8.9	10.0
90	4.4	6.7	6.7	8.9	8.3	10.0
100	3.9	5.6	6.7	7.8	8.3	9.4
110	3.3	4.4	5.6	6.7	6.7	7.8
120	3.3	4.4	5.6	6.7	7.2	7.8
130	3.3	5.0	5.6	6.7	6.7	7.8
140	2.8	4.4	5.0	5.6	6.7	6.7
150	2.8	4.4	5.0	5.6	6.7	6.7
160	2.2	4.4	4.4	5.6	6.7	6.7
170	2.2	3.3	4.4	5.0	5.6	6.1
180	2.2	3.3	3.9	4.4	5.6	5.6

DEPTH (cm)	TEMPERATURE (^{o}C)					
	JUN 17	JUN 21	JUN 28	JUL 5	JUL 12	JUL 19
0	13.3	17.8	21.1	21.1	21.1	17.8
2.5	14.4	17.8	20.0	21.1	20.0	17.8
5	14.4	16.7	18.9	21.1	18.9	17.8
7.5	14.4	16.7	18.9	21.1	18.3	17.2
10	15.0	16.1	18.9	21.1	17.8	17.2
12.5	14.4	15.6	17.8	20.0	16.7	16.7
15	14.4	15.6	17.8	20.0	16.7	16.7
17.5	14.4	15.6	17.8	19.4	16.7	16.7
20	14.4	15.6	17.8	19.4	16.7	16.7
22.5	14.4	15.6	17.8	19.4	16.7	17.2
25	15.0	15.6	17.8	19.4	16.7	17.2
27.5	14.4	15.0	12.2	18.9	16.7	17.2
30	14.4	14.4	16.7	18.3	16.1	16.7
32.5	14.4	14.4	16.7	18.3	16.1	16.7
35	14.4	14.4	16.7	17.8	16.1	16.7
37.5	14.4	14.4	16.7	17.8	16.1	16.7
40	14.4	14.4	16.1	17.8	16.1	16.7
42.5	13.9	13.9	15.6	17.2	15.6	16.7
45	13.9	13.9	15.6	17.2	15.6	16.7
47.5	13.3	13.3	15.6	16.7	15.6	16.1
50	13.3	13.3	15.0	16.1	15.6	16.1
52.5	13.3	13.3	15.0	16.1	15.6	16.1
55	13.3	13.3	14.4	15.6	15.6	16.1
57.5	13.3	13.3	14.4	15.6	15.6	16.1
60	12.8	12.8	14.4	15.6	15.6	16.1
62.5	12.8	13.3	14.4	15.6	15.6	16.1
65	12.8	12.8	14.4	15.6	15.0	15.6
67.5	12.8	12.8	13.9	15.6	15.0	15.6
70	12.2	12.2	13.9	15.0	15.0	15.6
72.5	12.2	12.2	13.3	15.0	14.4	15.0
75	11.7	12.2	13.3	15.0	14.4	15.0
77.5	11.7	12.2	13.3	14.4	14.4	15.0
80	11.7	12.2	13.3	14.4	14.4	15.0
82.5	11.1	11.7	13.3	14.4	13.9	14.4
85	11.1	11.7	12.8	13.9	13.9	14.4
87.5	11.1	11.7	12.8	13.9	13.9	14.4
90	10.6	11.1	12.2	13.3	13.3	14.4
100	10.0	11.1	11.7	12.8	13.3	13.3
110	8.9	9.4	10.0	11.1	11.7	12.2
120	8.9	10.0	10.0	11.1	12.2	12.2
130	8.9	10.0	10.0	11.1	12.2	12.2
140	7.8	8.9	9.4	10.0	11.1	11.1
150	7.8	8.9	9.4	10.0	10.6	11.1
160	7.8	8.9	8.9	10.0	10.0	11.1
170	6.7	7.2	7.8	8.3	8.9	9.4
180	6.7	7.2	7.8	8.3	8.9	10.0

DEPTH (cm)	TEMPERATURE (^{o}C)					
	JUL 26	AUG 2	AUG 9	AUG 16	AUG 23	AUG 30
0	22.2	19.4	23.9	14.4	13.3	17.2
2.5	21.7	18.3	23.9	14.4	13.9	16.7
5	20.6	17.8	22.2	15.0	13.9	16.1
7.5	20.0	17.2	21.7	14.4	13.9	15.6
10	18.9	16.7	21.1	15.6	14.4	14.4
12.5	18.3	16.1	20.0	15.0	13.3	15.0
15	18.3	16.1	20.0	15.6	14.4	15.0
17.5	18.3	16.1	19.4	15.6	14.4	15.0
20	18.3	16.1	18.9	15.6	14.4	15.0
22.5	17.8	16.1	18.9	15.6	14.4	15.0
25	18.3	16.7	18.9	16.1	14.4	15.0
27.5	17.8	16.7	18.3	16.1	14.4	15.0
30	17.8	16.7	18.3	15.6	14.4	15.0
32.5	17.8	16.7	17.8	15.6	14.4	14.4
35	17.2	16.7	17.8	15.6	14.4	14.4
37.5	17.2	16.7	17.8	15.6	14.4	14.4
40	16.7	16.7	17.8	15.6	13.9	14.4
42.5	16.7	16.1	17.2	15.6	13.9	14.4
45	16.7	16.1	17.2	15.6	13.9	14.4
47.5	16.7	16.1	16.7	15.6	13.9	14.4
50	16.1	16.1	16.7	15.6	13.3	13.9
52.5	16.1	16.1	16.7	15.6	13.9	13.9
55	16.1	15.6	16.1	15.6	13.3	13.9
57.5	16.1	16.1	16.1	15.6	13.9	13.9
60	15.6	16.1	16.1	15.6	13.9	13.9
62.5	16.1	16.1	16.1	15.6	13.9	13.9
65	15.6	16.1	16.1	15.6	13.9	13.9
67.5	15.6	16.1	16.1	15.6	13.9	13.9
70	15.0	15.6	15.6	15.6	13.3	13.3
72.5	15.0	15.6	15.6	15.6	13.3	13.3
75	14.4	15.6	15.6	15.0	13.3	13.9
77.5	14.4	15.6	15.6	15.6	13.3	13.9
80	15.0	15.6	15.6	15.6	13.9	13.3
82.5	14.4	15.0	15.0	14.4	13.3	13.3
85	14.4	15.0	15.0	14.4	13.3	13.3
87.5	14.4	15.0	15.0	14.4	13.3	13.3
90	13.9	14.4	14.4	14.4	13.3	13.3
100	13.3	14.4	14.4	14.4	13.3	12.8
110	12.2	12.8	12.8	12.2-	12.2	11.7
120	12.2	12.8	12.8	13.3	12.8	12.2
130	12.2	12.8	12.8	13.3	13.3	12.2
140	11.1	11.7	12.2	12.2	12.2	11.7
150	11.1	11.7	11.7	12.2	12.2	11.1
160	10.6	11.1	11.1	12.2	11.7	11.1
170	9.4	10.0	10.6	11.1	11.1	10.6
180	10.0	10.0	10.6	11.1	11.1	11.1

DEPTH (cm)	TEMPERATURE (^{o}C)					
	OCT 19	OCT 26	NOV 2	NOV 9	NOV 17	NOV 30
0	10.0	5.0	5.6	-0.6	-2.2	-2.8
2.5	8.9	5.0	5.6	1.1	-1.1	-2.2
5	8.9	5.0	5.6	1.1	-1.1	-2.2
7.5	5.6	5.0	4.4	1.1	-1.1	-2.2
10	8.3	5.0	4.4	1.7	-0.6	-1.7
12.5	7.2	4.4	3.9	1.1	-1.1	-1.7
15	7.8	5.0	4.4	1.7	-0.6	-1.7
17.5	7.8	5.0	4.4	2.2	-0.6	-1.7
20	7.8	5.6	4.4	2.2	0	-1.1
22.5	7.8	5.6	4.4	2.2	0	-1.1
25	7.8	6.1	4.4	3.3	0.6	-1.1
27.5	7.8	6.1	4.4	3.3	1.1	-1.1
30	7.8	6.1	4.4	3.3	1.1	-1.1
32.5	7.8	6.7	4.4	3.3	1.1	-1.1
35	7.8	6.7	4.4	3.3	1.1	-1.1
37.5	7.8	6.7	4.4	3.3	1.1	-0.6
40	7.8	6.7	4.4	3.9	1.7	-0.6
42.5	7.8	6.7	4.4	3.9	1.7	0
45	7.8	6.7	4.4	4.4	1.7	0
47.5	7.8	6.7	4.4	4.4	2.2	0
50	7.8	6.7	4.4	4.4	2.2	0
52.5	7.8	6.7	4.4	4.4	2.2	0
55	7.8	6.7	4.4	4.4	2.2	0
57.5	7.8	7.2	5.0	4.4	2.2	0.6
60	7.8	7.8	5.6	4.4	2.8	0.6
62.5	7.8	7.8	6.1	5.6	3.3	1.1
65	8.3	7.8	6.1	5.6	3.3	1.1
67.5	8.3	7.8	6.1	5.6	3.3	1.1
70	7.8	7.8	5.6	5.0	3.3	1.1
72.5	7.8	7.8	5.6	5.0	3.3	1.1
75	8.3	7.8	6.1	5.6	3.3	1.1
77.5	8.3	7.8	6.7	5.6	3.9	1.7
80	8.9	8.3	6.7	6.1	4.4	2.2
82.5	8.3	7.8	6.7	5.6	4.4	2.2
85	8.9	8.3	6.7	6.1	4.4	2.2
87.5	8.9	8.3	6.7	6.7	4.4	2.2
90	8.9	8.3	6.7	6.1	4.4	2.2
100	8.9	8.9	6.7	6.7	5.0	3.3
110	7.8	7.8	6.7	5.6	4.4	2.2
120	8.9	8.9	7.8	6.7	5.6	3.3
130	8.9	8.9	8.3	6.7	6.7	4.4
140	8.9	8.9	7.8	6.7	6.1	4.4
150	8.9	8.9	7.8	6.7	6.7	4.4
160	8.9	8.9	8.3	6.7	6.7	5.6
170	8.3	8.9	8.3	6.7	6.7	5.6
180	8.9	8.9	8.9	6.7	6.7	6.1

DEPTH (cm)	TEMPERATURE (^{o}C) 1978 - 1979					
	DEC 12	JAN 29	FEB 11	FEB 27	MAR 17	APR 1
0	-3.3	-5.0	-5.6	-6.7	0	-3.9
2.5	-2.8	-4.4	-5.0	-	0	-3.3
5	-2.8	-3.9	-	-	-0.6	-3.9
7.5	-2.8	-4.4	-	-6.1	-1.1	-3.9
10	-2.8	-3.9	-5.6	-6.1	-1.1	-3.3
12.5	-3.3	-5.0	-6.7	-6.7	-1.1	-3.3
15	-2.8	-4.4	-	-	-	-
17.5	-2.2	-3.9	-6.1	-6.1	-1.7	-3.3
20	-2.2	-3.9	-6.1	-5.6	-1.7	-3.3
22.5	-2.2	-3.9	-6.7	-5.6	-2.2	-3.3
25	-2.2	-3.3	-5.6	-5.6	-1.7	-2.2
27.5	-2.2	-3.3	-5.6	-5.6	-1.7	-2.2
30	-2.2	-3.3	-5.6	-5.6	-2.2	-2.2
32.5	-1.7	-3.3	-5.6	-5.6	-2.2	-2.2
35	-1.7	-3.3	-5.6	-5.6	-2.2	-2.2
37.5	-1.7	-3.3	-5.6	-5.0	-2.2	-
40	-1.1	-3.3	-5.6	-5.0	-2.2	-1.7
42.5	-1.1	-3.3	-5.6	-5.0	-2.2	-2.2
45	-1.1	-3.3	-5.6	-5.0	-2.2	-2.2
47.5	-1.1	-3.3	-5.6	-5.0	-2.2	-2.2
50	-1.1	-4.4	-5.0	-5.0	-2.8	-2.2
52.5	-1.1	-2.8	-4.4	-5.0	-2.2	-1.7
55	-1.1	-3.3	-5.0	-4.4	-2.2	-2.8
57.5	-0.6	-2.8	-4.4	-3.9	-1.7	-1.7
60	0	-2.2	-4.4	-3.9	-1.7	-1.7
62.5	0	-2.2	-	-	-	-0.6
65	0	-2.2	-2.8	-	-1.1	-0.6
67.5	0.6	-1.7	-5.0	-3.3	-1.1	-0.6
70	0	-2.2	-2.8	-3.3	-1.1	-1.1
72.5	0	-2.2	-2.8	-3.3	-1.1	-1.1
75	0	-2.2	-3.3	-3.3	-1.7	-1.1
77.5	0.6	-1.7	-2.8	-3.3	-1.1	-1.1
80	1.1	-1.1	-2.2	-2.8	-1.1	-1.1
82.5	1.1	-1.1	-2.8	-2.8	-1.7	-1.1
85	1.1	-1.1	-2.2	-2.2	-1.7	-1.1
87.5	1.7	-1.1	-2.2	-2.2	-1.7	-1.1
90	1.1	-1.1	-2.8	-2.8	-2.2	-1.7
100	1.7	-1.1	-1.1	-2.2	-1.7	-1.1
110	1.1	-0.6	-1.1	-2.2	-2.2	-1.7
120	2.2	-1.1	-0.6	-1.1	-1.1	-1.1
130	3.3	0	0.6	0	-1.1	0
140	3.3	1.1	0	-0.6	-1.1	0
150	3.3	0.6	0.6	0	-1.1	0
160	3.9	1.1	0.6	0	-0.6	0
170	3.9	1.1	0.6	0	-0.6	0
180	4.4	2.2	1.1	1.1	0.6	1.1

DEPTH (cm)	TEMPERATURE (^oC)					
	APR 13	APR 27	MAY 8	MAY 18	MAY 25	JUN 8
0	2.2	3.3	3.3	8.9	12.8	12.2
2.5	2.2	2.8	3.3	8.9	12.2	11.1
5	2.2	2.2	2.8	7.8	11.7	10.6
7.5	1.1	1.7	2.8	7.8	11.1	10.0
10	1.1	1.7	2.8	7.8	11.1	10.0
12.5	1.1	0	2.2	6.7	10.0	8.9
15	-	-	2.2	6.7	10.0	9.4
17.5	1.1	0	2.2	6.7	10.0	10.0
20	0.6	0	2.2	6.7	10.0	10.0
22.5	0	0	1.7	6.1	9.4	9.4
25	0	0	2.2	6.1	9.4	10.0
27.5	-1.1	0	2.2	5.6	8.9	10.0
30	-1.1	-0.6	1.1	5.6	8.9	9.4
32.5	-1.1	-1.1	1.1	5.6	8.9	9.4
35	-1.1	-1.1	1.1	4.4	7.8	8.9
37.5	-	-	-	-	-	-
40	-	-1.1	1.1	4.4	7.8	9.4
42.5	-1.1	-1.1	0.6	3.9	6.7	8.9
45	-1.1	-1.7	0.6	3.9	6.7	8.9
47.5	-1.1	-1.1	0	3.3	6.7	8.3
50	-1.7	-1.7	-1.1	2.2	5.6	7.8
52.5	-1.1	-1.7	0	3.3	6.1	8.3
55	-2.2	-	-1.1	1.7	4.4	6.7
57.5	-1.1	-1.7	-0.6	2.8	5.6	8.3
60	0	-	-0.6	2.2	5.0	7.8
62.5	1.1	-1.7	0	2.8	5.6	7.8
65	1.1	-1.7	-1.1	2.2	4.4	7.8
67.5	1.1	-1.1	-0.6	2.2	4.4	7.8
70	1.1	-1.7	-1.1	1.1	3.9	7.2
72.5	1.1	-1.7	-1.1	1.1	3.9	7.2
75	0	-1.7	-1.1	1.1	3.9	6.7
77.5	0	-1.7	-1.1	1.1	3.9	7.2
80	0	-1.1	-1.1	1.1	3.9	7.2
82.5	0	-1.7	-1.1	0	3.3	6.7
85	-1.1	-1.1	-1.1	0	3.3	6.7
87.5	0	-1.1	-1.1	0	3.3	6.7
90	-1.1	-1.7	-1.7	-1.1	2.8	6.1
100	-1.1	-1.1	-1.1	-1.1	2.2	6.1
110	-1.1	-2.2	-1.7	-1.7	1.1	4.4
120	-1.1	-1.1	-1.1	-1.1	1.1	4.4
130	0	0	0	0	1.7	4.4
140	-0.6	-	-	-	1.1	0.6
150	0	-0.6	-1.1	0	0.6	2.8
160	0	0	-0.6	0	0	2.2
170	0	0	-0.6	0	0	2.2
180	1.1	-	-0.6	0.6	1.1	2.8

DEPTH (cm)	TEMPERATURE (°C)					
	JUN 15	JUN 23	JUN 29	JUL 5	JUL 15	JUL 20
0	12.8	15.6	21.1	21.1	16.7	21.1
2.5	12.2	15.6	19.4	20.0	15.6	20.6
5	12.2	15.0	18.3	18.9	15.6	20.0
7.5	12.2	14.4	17.2	18.3	15.0	18.9
10	12.2	14.4	16.7	18.3	15.6	18.9
12.5	11.1	13.3	15.6	16.7	14.4	17.8
15	11.7	13.3	15.6	17.2	14.4	18.3
17.5	11.7	13.3	15.6	17.2	14.4	18.3
20	11.7	13.3	15.6	16.7	14.4	17.8
22.5	11.7	13.3	15.0	16.7	14.4	17.8
25	11.7	13.3	15.0	16.7	14.4	17.8
27.5	11.7	13.3	14.4	16.1	14.4	17.8
30	11.1	12.8	14.4	15.6	14.4	17.8
32.5	11.7	12.8	14.4	15.6	14.4	17.2
35	11.1	12.2	13.3	15.6	13.3	16.7
37.5	-	-	-	-	-	-
40	11.1	12.2	13.3	15.0	14.4	16.7
42.5	10.6	11.7	13.3	14.4	13.3	15.6
45	10.6	11.7	13.3	14.4	13.3	15.6
47.5	10.0	11.1	12.2	13.9	13.3	15.6
50	9.4	10.0	11.1	13.3	12.2	14.4
52.5	10.0	11.1	12.2	13.3	13.3	14.4
55	8.3	9.4	10.0	13.3	11.7	13.3
57.5	10.0	10.6	11.7	11.7	13.3	14.4
60	9.4	10.6	11.7	12.8	13.3	14.4
62.5	10.0	10.6	11.7	12.2	13.3	14.4
65	9.4	10.0	11.1	12.2	13.3	13.3
67.5	9.4	10.0	11.1	11.7	13.3	13.3
70	8.9	9.4	10.0	11.1	12.2	12.8
72.5	8.3	8.9	10.0	11.1	12.2	12.8
75	8.3	8.9	10.0	11.7	12.2	12.8
77.5	8.3	8.9	10.0	11.7	12.2	12.8
80	8.3	8.9	10.0	11.1	12.2	12.8
82.5	7.8	8.9	10.0	11.1	12.2	12.2
85	8.3	8.9	10.0	11.1	12.2	12.2
87.5	7.8	8.9	10.0	10.0	12.2	12.2
90	7.2	7.8	8.9	10.0	11.1	11.1
100	7.2	7.8	8.9	8.9	11.1	11.1
110	5.6	6.7	7.2	8.9	9.4	9.4
120	5.6	6.7	7.2	8.9	10.0	10.0
130	5.6	6.7	7.2	5.6	10.0	10.0
140	-	4.4	-	6.1	-	- 0
150	3.9	4.4	5.6	6.1	7.8	7.8
160	3.9	4.4	4.4	5.6	7.8	7.2
170	3.3	3.9	4.4	5.6	6.7	7.2
180	3.9	4.4	4.4	5.6	7.2	7.2

DEPTH (cm)	TEMPERATURE (°C)					
	JUL 27	AUG 6	AUG 10	AUG 17	AUG 24	SEP 7
0	18.9	16.7	17.8	19.4	15.6	12.2
2.5	18.3	15.6	16.7	18.3	15.6	12.2
5	17.8	15.6	15.6	17.8	15.6	12.8
7.5	16.7	15.6	15.6	17.2	15.0	12.8
10	16.7	15.6	15.0	16.7	15.6	12.8
12.5	15.6	14.4	13.9	15.0	14.4	13.3
15	15.6	15.0	14.4	15.6	15.0	12.2
17.5	15.6	15.6	14.4	15.6	15.6	12.8
20	15.6	15.6	14.4	15.0	15.6	13.3
22.5	15.6	14.4	13.3	15.0	15.0	13.3
25	15.6	15.6	14.4	15.0	15.6	11.7
27.5	15.6	15.6	14.4	15.0	15.6	13.3
30	15.6	15.6	13.9	15.0	15.6	13.3
32.5	15.6	15.6	13.9	15.0	15.6	13.3
35	15.6	14.4	13.3	14.4	15.0	13.3
37.5	-	-	-	-	-	-
40	15.6	15.6	13.9	14.4	15.6	13.3
42.5	15.0	14.4	13.3	13.9	14.4	13.3
45	15.0	14.4	13.3	13.9	14.4	13.3
47.5	14.4	14.4	13.9	13.9	14.4	13.3
50	13.3	13.3	12.8	13.3	13.3	12.2
52.5	14.4	14.4	13.3	13.3	14.4	13.3
55	12.2	12.2	11.1	11.7	12.2	11.1
57.5	14.4	14.4	13.3	13.9	14.4	13.3
60	14.4	14.4	13.3	13.9	14.4	13.3
62.5	14.4	14.4	13.3	13.9	14.4	13.3
65	13.9	14.4	13.3	13.3	13.9	13.3
67.5	14.4	14.4	13.3	13.9	14.4	13.3
70	13.3	13.3	12.8	12.8	13.3	12.8
72.5	13.3	13.3	12.8	13.3	13.3	12.8
75	13.3	13.3	12.8	12.8	13.3	12.8
77.5	13.3	13.3	12.8	13.3	13.3	13.3
80	13.9	13.3	12.8	13.3	13.3	13.3
82.5	12.8	13.3	12.2	12.2	13.3	12.2
85	12.8	13.3	12.8	12.8	13.3	12.8
87.5	12.8	13.3	12.2	12.2	12.8	12.2
90	12.2	12.2	11.1	11.7	12.2	12.2
100	12.2	12.2	11.7	11.7	12.2	12.2
110	10.0	11.1	10.0	10.0	10.0	10.0
120	10.0	11.1	10.6	10.6	11.1	11.1
130	10.6	11.1	10.6	11.1	11.1	11.1
140	8.9	-	-	-	-	-
150	8.3	8.9	8.9	8.9	8.9	9.4
160	7.8	8.9	8.9	8.9	8.9	8.9
170	7.8	7.8	7.8	8.3	8.9	8.9
180	7.8	8.9	8.3	8.9	8.9	10.0

DEPTH (cm)	TEMPERATURE (°C)					
	SEP 14	SEP 21	OCT 5	OCT 12	NOV 19	DEC 13
0	14.4	10.0	6.7	7.8	-3.3	-6.7
2.5	13.3	10.0	7.2	7.8	-2.2	-5.6
5	12.8	10.0	7.8	7.2	-1.7	-4.4
7.5	12.2	10.0	7.8	7.8	-1.7	-4.4
10	12.2	11.1	7.8	6.7	-1.1	-3.9
12.5	10.6	10.0	7.2	6.1	-1.7	-4.4
15	11.1	11.1	8.3	7.8	-1.1	-3.3
17.5	11.1	11.1	8.9	8.3	0	-2.8
20	11.1	11.1	8.9	8.3	0	-2.8
22.5	11.1	11.1	8.9	7.8	0	-2.8
25	11.1	11.7	8.9	7.2	0.6	-2.2
27.5	11.1	11.7	8.9	8.9	1.1	-1.7
30	11.1	11.7	8.9	8.9	1.1	-1.7
32.5	11.1	12.2	9.4	8.9	1.1	-1.1
35	11.1	11.1	8.9	8.3	1.1	-1.1
37.5	-	-	-	-	-	-
40	11.7	12.2	10.0	8.3	2.2	0
42.5	11.1	12.2	9.4	8.9	1.7	-1.1
45	11.1	12.2	9.4	8.9	1.7	-1.1
47.5	11.1	11.7	9.4	8.9	1.7	-1.1
50	10.0	11.1	8.9	7.8	1.1	-1.1
52.5	11.1	12.2	10.0	8.9	2.2	0
55	8.9	8.9	7.2	6.7	-0.6	-2.8
57.5	11.1	11.7	10.0	8.9	2.2	0
60	11.1	11.7	10.0	8.9	2.2	0
62.5	11.1	12.2	10.0	8.9	2.8	1.1
65	11.1	12.2	10.0	8.9	2.2	1.7
67.5	11.7	12.2	10.0	9.4	3.3	1.1
70	10.6	11.1	10.0	8.9	2.2	0.6
72.5	11.1	11.1	10.0	8.9	2.8	0.6
75	11.1	11.1	10.0	8.9	2.8	0.6
77.5	11.1	11.7	10.0	8.9	3.3	1.1
80	11.1	11.1	10.0	8.9	3.3	1.1
82.5	10.6	11.1	10.0	8.9	3.3	1.1
85	11.1	11.1	10.0	8.9	3.3	1.1
87.5	10.6	11.1	10.0	8.9	3.3	-1.1
90	10.0	10.0	9.4	8.3	3.3	1.1
100	10.0	11.1	10.0	8.9	3.9	1.7
110	8.9	9.4	8.9	7.8	3.3	1.1
120	8.9	10.0	9.4	8.9	4.4	2.2
130	10.0	10.6	10.0	8.9	5.6	3.3
140	-	-	8.9	7.8	-	-
150	8.3	8.9	8.9	7.8	4.4	2.2
160	8.3	8.9	8.9	7.8	5.0	3.3
170	8.3	8.9	8.9	7.8	5.6	3.3
180	8.9	9.4	8.9	8.9	6.7	4.4

DEPTH (cm)	TEMPERATURE (°C) 1980		
	JAN 3	FEB 5	MAR 21
0	-4.4	-5.6	-3.3
2.5	-4.4	-5.6	-2.8
5	-4.4	-4.4	-3.3
7.5	-4.4	-3.9	-3.3
10	-3.9	-3.9	-3.3
12.5	-4.4	-4.4	-3.9
15	-4.4	-3.9	-3.3
17.5	-3.9	-3.3	-3.3
20	-3.9	-3.3	-3.3
22.5	-3.9	-3.9	-3.3
25	-3.3	-3.3	-3.3
27.5	-3.3	-3.3	-3.3
30	-3.3	-3.3	-3.3
32.5	-2.8	-3.3	-3.9
35	-3.3	-3.3	-3.3
37.5	-	-	-
40	-2.2	-2.8	-3.3
42.5	-2.2	-3.3	-3.3
45	-2.2	-3.3	-3.3
47.5	-2.2	-3.3	-3.3
50	-2.8	-3.3	-3.9
52.5	-1.7	-2.2	-2.8
55	-4.4	-6.1	-7.8
57.5	-1.1	-2.2	-2.8
60	-1.1	-2.2	-2.8
62.5	-1.1	-1.7	-2.2
65	-1.1	-1.7	-2.8
67.5	-0.6	-1.1	-2.2
70	-1.1	-1.7	-3.3
72.5	-1.1	-1.7	-2.8
75	-0.6	-1.7	-
77.5	0	-1.1	-2.2
80	-0.6	-1.7	-2.2
82.5	0	-1.1	-2.2
85	0	-1.1	-2.2
87.5	0	-1.1	-2.2
90	-0.6	-1.7	-2.2
100	0	-1.1	-2.2
110	-0.6	-1.7	-3.3
120	1.1	-0.6	-1.1
130	1.7	0	-0.6
140	-	-	-
150	1.1	-1.1	-1.1
160	1.7	0	-1.1
170	2.2	0.6	-0.6
180	3.3	1.7	0.6

Appendix 2: Soil temperatures in ^{o}C at Paulencu site.

DEPTH (cm)	TEMPERATURE (°C) 1978					
	MAY 12	MAY 17	MAY 24	MAY 31	JUN 7	JUN 14
0	11.1	17.2	11.7	14.4	22.2	13.3
2.5	11.1	15.6	11.7	13.3	21.1	13.3
5	10.6	13.3	11.7	12.2	20.0	13.3
7.5	10.0	11.7	11.7	11.1	18.3	13.3
10	8.3	8.9	10.0	8.9	15.6	11.7
12.5	10.0	10.0	12.2	10.6	16.7	14.4
15	10.0	10.0	12.2	10.0	16.1	14.4
17.5	10.6	10.0	12.2	10.0	15.6	14.4
20	10.6	10.0	12.2	10.0	15.6	14.4
22.5	10.0	9.4	12.2	10.0	15.0	14.4
25	10.0	8.9	12.2	10.0	15.0	14.4
27.5	10.0	8.9	12.2	10.0	14.4	14.4
30	10.0	8.9	12.2	10.0	14.4	14.4
32.5	9.4	8.3	11.7	9.4	13.9	13.3
35	9.4	8.9	11.7	9.4	14.4	13.3
37.5	9.4	8.9	11.7	9.4	14.4	13.3
40	8.9	8.3	11.1	9.4	13.9	13.3
42.5	-	-	-	-	-	-
45	8.9	8.3	11.1	9.4	13.3	13.3
47.5	8.9	7.8	11.1	9.4	13.3	13.3
50	8.9	7.8	10.6	8.9	13.3	12.8
52.5	8.9	7.8	10.6	8.9	13.3	12.8
55	8.9	7.8	10.0	8.9	12.8	12.2
57.5	8.3	7.8	10.0	8.9	12.2	12.2
60	8.3	7.2	10.0	8.9	12.2	12.2
62.5	7.8	6.7	9.4	8.9	11.7	12.2
65	8.3	6.7	9.4	8.9	11.7	12.2
67.5	8.3	6.7	8.9	8.9	11.7	12.2
70	7.8	6.7	8.3	8.3	11.1	11.1
72.5	6.1	5.0	6.7	6.7	8.9	10.0
75	7.8	6.7	8.3	8.3	11.1	11.1
77.5	7.8	6.1	8.3	8.3	10.6	11.1
80	7.8	6.1	8.3	8.3	10.0	11.1
82.5	7.8	5.6	7.8	7.8	10.0	10.6
85	5.6	3.9	5.6	8.3	7.8	8.3
87.5	7.2	5.6	7.8	7.8	10.0	10.0
90	0.6	-1.1	0.6	1.1	2.8	3.3
100	6.7	5.0	6.7	7.2	8.3	9.4
110	5.6	3.3	5.0	5.6	6.7	7.8
120	3.9	1.7	2.8	3.3	4.4	5.6
130	6.1	3.3	5.0	5.6	6.7	7.8
140	6.1	3.3	4.4	5.6	6.7	7.2
150	5.6	3.3	4.4	5.0	6.1	6.7
160	5.6	3.3	4.4	5.0	5.6	6.7
170	6.7	3.3	4.4	4.4	5.6	6.1
180	7.2	2.8	3.9	4.4	5.0	5.6

DEPTH (cm)	TEMPERATURE (^{o}C)					
	JUN 21	JUN 28	JUL 5	JUL 12	JUL 19	JUL 26
0	23.9	25.0	21.1	17.8	21.7	22.2
2.5	22.2	25.0	21.1	17.8	20.6	21.1
5	20.0	21.7	20.0	16.7	18.9	20.0
7.5	18.3	20.0	20.0	16.7	17.8	18.9
10	15.6	17.8	17.8	14.4	15.6	16.7
12.5	16.7	18.9	20.0	16.7	17.2	18.9
15	16.1	18.3	20.0	16.7	17.2	18.9
17.5	15.6	17.8	20.0	17.2	17.2	18.9
20	15.6	17.8	20.0	17.8	17.2	18.9
22.5	15.0	17.2	20.0	17.8	16.7	18.9
25	15.0	17.2	19.4	17.8	16.7	18.9
27.5	14.4	16.7	19.4	17.8	16.7	18.9
30	14.4	16.7	19.4	17.8	16.7	18.3
32.5	13.9	16.1	18.9	17.2	16.7	17.8
35	14.4	16.1	18.9	17.8	16.7	18.3
37.5	14.4	16.1	18.9	17.8	16.7	18.3
40	13.9	15.6	18.3	17.2	16.7	17.8
42.5	-	-	-	-	-	-
45	13.3	15.6	17.8	16.7	16.7	17.8
47.5	13.3	15.6	17.8	16.7	16.7	17.8
50	12.8	15.0	17.2	16.7	16.7	17.2
52.5	13.3	15.0	17.2	16.7	16.7	17.2
55	12.8	14.4	16.7	16.7	16.7	17.2
57.5	12.8	14.4	16.7	16.7	16.7	16.7
60	12.2	13.9	16.1	16.1	16.7	16.1
62.5	12.2	13.9	15.6	16.1	16.1	16.1
65	12.2	13.3	15.6	16.1	16.1	16.1
67.5	12.2	13.3	15.6	15.6	16.1	16.1
70	11.7	12.8	15.0	15.6	15.6	15.6
72.5	10.0	11.1	13.3	13.9	13.9	13.9
75	11.7	12.8	15.0	15.6	15.6	15.6
77.5	11.1	12.2	14.4	15.0	15.0	15.6
80	11.1	12.2	14.4	15.0	15.0	15.6
82.5	11.1	12.2	14.4	14.4	14.4	15.0
85	8.9	10.0	12.2	12.2	12.2	12.8
87.5	10.6	11.7	13.9	14.4	14.4	14.4
90	3.9	5.0	6.7	7.2	7.8	7.8
100	10.0	11.1	12.8	13.3	13.3	13.9
110	8.3	8.9	10.6	11.7	12.2	12.2
120	6.7	6.7	8.3	9.4	9.4	10.0
130	8.3	8.9	10.0	11.1	11.7	12.2
140	8.3	8.9	10.0	11.1	11.1	12.2
150	7.8	8.3	9.4	10.6	11.1	11.7
160	7.2	7.8	8.9	10.0	10.6	11.1
170	7.2	7.8	8.9	10.0	10.0	10.6
180	6.7	6.7	7.8	9.4	9.4	10.0

DEPTH (cm)	TEMPERATURE (°C)					
	AUG 2	AUG 9	AUG 16	AUG 23	AUG 30	SEP 6
0	17.2	23.9	14.4	15.6	15.6	14.4
2.5	16.1	23.9	14.4	15.6	15.6	14.4
5	15.6	22.8	14.4	15.0	14.4	14.4
7.5	15.0	21.1	15.0	15.0	14.4	14.4
10	13.3	18.3	13.3	13.3	13.3	13.3
12.5	15.6	19.4	15.6	15.0	15.6	15.6
15	15.6	18.9	16.1	15.6	15.6	15.6
17.5	16.1	18.9	16.7	15.6	15.6	15.6
20	16.7	18.9	16.7	15.6	15.6	15.6
22.5	16.7	18.3	16.7	15.6	15.6	15.6
25	16.7	18.3	16.7	15.6	15.6	15.6
27.5	16.7	18.3	16.7	15.6	15.6	15.6
30	16.7	18.3	16.7	15.6	15.6	15.6
32.5	16.7	17.8	16.7	15.0	15.6	15.6
35	17.2	17.8	17.2	15.6	15.6	15.6
37.5	17.8	17.8	17.2	15.6	15.6	15.6
40	17.2	17.8	16.7	15.0	15.6	15.6
42.5	-	-	-	-	15.6	15.6
45	17.2	17.8	16.7	15.0	15.6	15.6
47.5	17.2	17.8	16.7	15.0	15.6	15.6
50	17.2	17.2	16.7	14.4	15.0	15.6
52.5	17.2	17.2	16.7	14.4	15.0	15.6
55	16.7	16.7	16.7	14.4	15.0	15.6
57.5	16.7	16.7	16.7	14.4	15.0	15.6
60	16.7	16.7	16.7	14.4	14.4	15.6
62.5	16.7	16.1	16.1	14.4	14.4	15.6
65	16.7	16.1	16.1	14.4	14.4	15.6
67.5	16.7	16.1	16.1	14.4	14.4	15.6
70	16.1	15.6	15.6	13.9	13.9	14.4
72.5	14.4	13.9	13.9	12.2	12.2	13.3
75	16.1	15.6	15.6	14.4	14.4	15.0
77.5	15.6	15.6	15.6	14.4	14.4	14.4
80	15.6	15.6	15.6	14.4	14.4	14.4
82.5	15.6	15.0	15.6	13.9	13.9	14.4
85	13.3	12.8	13.3	12.2	12.2	12.2
87.5	15.0	14.4	15.6	13.9	13.9	14.4
90	8.3	7.8	8.3	12.8	7.2	7.2
100	14.4	14.4	14.4	13.9	13.9	13.9
110	12.8	12.2	12.8	12.2	12.2	12.2
120	10.6	10.0	10.6	10.0	10.0	10.0
130	12.2	12.2	12.2	12.2	12.2	12.2
140	12.2	12.2	12.2	12.2	12.2	12.2
150	12.2	11.7	12.2	12.2	12.2	12.2
160	11.7	11.1	12.2	11.7	12.2	12.2
170	11.1	11.1	11.1	11.7	11.7	11.7
180	10.6	10.0	11.1	11.1	11.7	11.7

DEPTH (cm)	TEMPERATURE (°C)					
	SEP 13	SEP 20	SEP 26	OCT 4	OCT 11	OCT 19
0	12.2	12.2	10.0	7.8	7.8	8.9
2.5	12.2	11.1	8.9	7.8	7.8	7.8
5	11.1	10.0	7.2	6.7	6.7	6.7
7.5	11.1	8.9	6.7	7.2	6.7	7.2
10	9.4	7.2	5.6	5.6	5.0	5.6
12.5	11.7	8.9	7.2	7.8	6.7	7.8
15	12.2	8.9	7.2	7.8	7.2	7.8
17.5	12.2	9.4	7.8	8.3	7.8	7.8
20	12.2	9.4	7.8	8.3	7.8	7.8
22.5	12.2	9.4	7.8	8.3	7.8	7.8
25	12.2	10.0	7.8	8.3	7.8	7.8
27.5	12.8	10.0	7.8	8.9	7.8	7.8
30	13.3	10.0	7.8	8.9	8.3	7.8
32.5	12.8	10.0	7.8	8.9	7.8	7.8
35	13.3	10.6	8.3	8.9	8.3	7.8
37.5	13.3	11.1	8.3	9.4	8.9	7.8
40	13.3	11.1	8.3	9.4	8.3	7.8
42.5	-	-	-	-	5.0	3.9
45	13.3	11.1	8.3	9.4	8.9	7.8
47.5	13.9	11.1	8.9	9.4	8.9	7.8
50	13.9	11.1	8.9	9.4	8.9	7.8
52.5	13.9	11.7	8.9	10.0	8.9	7.8
55	13.9	11.7	8.9	10.0	8.9	7.8
57.5	13.9	10.6	8.9	10.0	8.9	7.8
60	13.9	10.6	8.9	10.0	8.9	7.8
62.5	13.9	10.6	8.9	9.4	8.9	7.8
65	13.9	11.1	8.9	10.0	8.9	7.8
67.5	14.4	11.1	8.9	10.0	9.4	8.3
70	13.3	10.6	7.2	9.4	8.9	7.8
72.5	12.2	-	7.2	8.3	7.8	6.7
75	13.9	11.1	8.9	10.0	8.9	8.3
77.5	13.9	11.1	8.9	10.0	8.9	8.3
80	13.9	11.1	9.4	10.0	9.4	8.3
82.5	13.3	11.1	8.9	10.0	8.9	8.3
85	11.7	-	7.8	7.8	7.8	6.7
87.5	13.3	11.1	8.9	10.0	8.9	8.3
90	6.7	-	3.3	3.9	-	2.2
100	13.3	11.7	9.4	10.0	9.4	8.9
110	12.2	10.0	8.3	8.9	8.3	7.8
120	10.0	-	7.8	7.8	7.2	6.7
130	12.2	10.6	8.9	9.4	8.9	8.9
140	12.2	10.6	8.9	10.0	9.4	8.9
150	12.2	11.1	9.4	10.0	9.4	8.9
160	12.2	11.1	8.9	10.0	9.4	8.9
170	11.7	11.1	8.9	10.0	9.4	8.9
180	11.1	10.6	8.9	9.4	8.9	8.9

DEPTH (cm)	TEMPERATURE (°C)					
	OCT 26	NOV 2	NOV 9	NOV 16	NOV 29	DEC 12
0	3.3	6.7	-1.7	-2.2	-3.9	-2.2
2.5	3.3	5.6	-1.1	-2.2	-3.9	-2.2
5	2.8	4.4	-1.1	-2.8	-3.9	-
7.5	3.3	4.4	0	-2.2	-3.3	-2.2
10	2.2	2.2	-1.1	-3.3	-4.4	-4.4
12.5	4.4	4.4	1.1	-1.7	-2.8	-3.3
15	4.4	4.4	1.7	-1.1	-2.2	-3.3
17.5	4.4	4.4	2.2	-1.1	-2.2	-2.8
20	5.0	4.4	2.2	-0.6	-2.2	-2.8
22.5	5.0	4.4	2.2	-0.6	-2.2	-2.8
25	5.0	4.4	2.2	-0.6	-2.2	-2.2
27.5	5.6	4.4	2.8	0	-1.7	-2.2
30	5.6	4.4	3.3	0	-	-2.2
32.5	5.6	4.4	2.8	0	-	-2.2
35	5.6	4.4	3.3	0.6	-1.1	-2.2
37.5	6.1	4.4	4.4	1.1	-1.1	-1.7
40	6.1	4.4	3.3	1.1	-1.1	-1.7
42.5	-	-	0.6	-2.2	-	-
45	6.7	4.4	4.4	1.7	-1.1	-1.1
47.5	6.7	5.0	4.4	1.7	-1.1	-1.1
50	6.7	5.0	4.4	2.2	-0.6	-1.1
52.5	6.7	5.0	4.4	2.2	0	-1.1
55	5.7	5.0	4.4	2.2	0	-1.1
57.5	7.2	5.6	4.4	2.8	0	-0.6
60	7.2	5.6	4.4	2.8	0	-0.6
62.5	6.7	5.6	4.4	2.2	0	-1.1
65	7.2	5.6	4.4	2.8	0.6	-0.6
67.5	7.8	5.6	5.0	3.3	1.1	0
70	6.7	5.6	4.4	3.3	0.6	-0.6
72.5	5.6	4.4	8.9	-1.7	-1.1	-2.2
75	7.8	6.1	4.4	3.3	-	0
77.5	7.8	6.1	5.0	3.3	1.1	0
80	7.8	6.7	5.6	3.9	1.7	0
82.5	7.8	6.7	5.6	3.9	1.1	0
85	5.6	4.4	3.9	2.2	0	-1.1
87.5	7.8	6.7	5.6	4.4	2.2	1.1
90	1.7	0.6	0	-1.7	-3.9	-4.4
100	8.3	7.2	6.1	4.4	-	1.7
110	7.2	6.7	5.6	4.4	-	1.1
120	6.1	5.6	4.4	3.3	1.1	0
130	7.8	7.8	6.7	5.6	3.9	2.2
140	8.9	7.8	7.8	6.7	4.4	3.3
150	8.9	8.3	7.8	6.7	5.6	3.3
160	8.9	8.3	7.8	6.7	5.6	3.9
170	8.9	8.3	7.8	6.7	5.6	4.4
180	8.9	8.3	7.8	7.2	5.6	4.4

DEPTH (cm)	TEMPERATURE ($^{\circ}$C) 1979					
	JAN 29	FEB 11	MAR 17	APR 1	APR 13	APR 27
0	-6.1	-6.7	-1.7	-5.6	0	5.0
2.5	-5.0	-6.7	-1.7	-5.6	-0.6	3.3
5	-5.6	-6.7	-2.2	-6.7	-1.1	1.1
7.5	-5.6	-6.7	-2.2	-5.6	-1.1	1.1
10	-7.2	-7.8	-3.9	-7.2	-2.2	-2.2
12.5	-5.6	-6.1	-2.2	-5.6	-1.1	-0.6
15	-	-	-	-	-	-
17.5	-4.4	-5.6	-2.2	-5.0	-1.1	-0.6
20	-4.4	-5.6	-2.2	-5.0	-1.1	-1.1
22.5	-4.4	-5.6	-2.2	-5.0	-1.1	-1.1
25	-4.4	-5.6	-1.7	-4.4	-1.1	-1.1
27.5	-4.4	-5.6	-1.7	-4.4	-1.1	-1.1
30	-4.4	-5.6	-2.2	-4.4	-1.1	-1.1
32.5	-4.4	-5.6	-2.8	-4.4	-1.7	-1.7
35	-3.9	-5.0	-2.2	-3.9	-1.7	-1.1
37.5	-3.9	-4.4	-2.2	-3.3	-1.7	-1.1
40	-3.9	-	-2.2	-3.3	-1.7	-1.7
42.5	-	-4.4	-	-	-	-
45	-3.3	-4.4	-3.3	-3.3	-1.1	-1.7
47.5	-3.3	-4.4	-2.2	-3.3	-1.1	-1.7
50	-3.3	-3.9	-2.2	-2.8	-1.7	-1.7
52.5	-2.8	-3.9	-2.2	-2.2	-1.1	-1.7
55	-2.8	-3.9	-2.2	-2.8	-1.1	-1.7
57.5	-2.8	-3.3	-1.7	-2.2	-1.1	-1.7
60	-2.2	-3.3	-1.1	-2.2	-1.1	-1.7
62.5	-2.8	-3.3	-1.7	-2.8	-1.7	-1.7
65	-2.2	-3.3	-	-	-	-
67.5	-2.2	-2.8	-2.2	-2.2	-1.7	-1.7
70	-2.2	-3.3	-2.2	-2.8	-2.2	-2.2
72.5	-3.3	-4.4	-3.3	-3.9	-3.3	-3.3
75	-1.7	-2.8	-1.1	-2.2	-2.2	-
77.5	-1.7	-2.2	-1.1	-2.2	-2.2	-1.7
80	-1.7	-2.2	-1.1	-2.2	-2.2	-1.7
82.5	-1.7	-2.2	-2.2	-2.2	-2.2	-3.3
85	-3.3	-3.3	-3.3	-3.9	-3.3	-3.3
87.5	-1.1	-2.2	-1.1	-2.2	-2.2	-1.7
90	-6.7	-	-6.7	-7.8	-7.8	-7.8
100	-0.6	-1.1	-1.1	-1.7	-1.1	-1.7
110	-1.1	-1.1	-1.1	-2.2	-2.2	-2.2
120	-2.2	-2.2	-2.2	-3.3	-3.3	-3.3
130	0	-0.6	-3.3	-1.7	-1.1	-1.7
140	1.1	0	-1.1	-1.1	0	-1.1
150	1.1	0.6	-0.6	-0.6	0	-0.6
160	1.1	1.1	0	0	0.6	-0.6
170	1.7	1.1	-0.6	0	1.1	0
180	2.2	1.7	0	0.6	1.1	0.6

DEPTH (cm)	TEMPERATURE (°C)					
	MAY 8	MAY 18	MAY 25	JUN 8	JUN 15	JUN 23
0	7.8	11.1	15.0	14.4	17.2	15.6
2.5	6.7	10.0	13.9	13.3	16.1	15.6
5	3.3	7.8	11.1	10.6	13.3	13.3
7.5	3.3	7.8	11.1	10.6	12.8	14.4
10	1.1	8.3	8.9	8.3	10.0	13.9
12.5	2.2	6.7	10.0	10.0	11.7	13.9
15	1.1	6.7	10.0	9.4	11.1	13.3
17.5	1.1	6.7	10.0	9.4	11.1	13.3
20	1.1	5.6	8.9	8.9	10.6	13.3
22.5	0.6	5.6	8.9	8.9	10.6	13.3
25	0	4.4	7.8	8.3	10.0	12.8
27.5	0	4.4	7.8	8.3	10.0	12.8
30	-0.6	4.4	7.8	8.3	10.0	12.8
32.5	-1.1	3.9	6.7	7.8	9.4	12.2
35	-1.1	3.9	6.7	8.3	10.0	12.2
37.5	-1.1	3.3	6.7	7.8	9.4	12.2
40	-1.1	3.3	6.1	7.8	9.4	11.7
42.5	-	-	-	-	-	-
45	-1.1	2.8	5.6	7.8	9.4	11.7
47.5	-1.1	2.8	5.6	7.8	9.4	11.1
50	-1.7	2.2	5.0	7.8	8.9	11.1
52.5	-1.7	2.2	4.4	7.8	8.9	11.1
55	-1.7	1.7	4.4	7.2	8.9	10.0
57.5	-1.7	1.7	4.4	7.2	8.9	10.0
60	-2.2	1.1	3.9	6.7	8.3	10.0
62.5	12.2	14.4	17.8	21.1	-	-
65	-	-	-	-	-	-
67.5	-1.7	0	3.3	6.7	8.3	10.0
70	-2.2	-1.1	2.2	5.6	7.8	8.9
72.5	-3.3	-2.2	1.1	4.4	5.6	7.2
75	-2.2	-1.1	2.2	5.6	7.2	8.9
77.5	-2.2	-1.1	2.2	5.6	7.2	8.3
80	-2.2	-1.1	2.2	5.6	7.2	8.3
82.5	-2.2	-1.7	1.1	5.0	6.7	7.8
85	-2.2	-2.8	-1.1	3.3	5.0	6.1
87.5	-2.2	-1.1	0.6	5.0	6.1	7.8
90	-7.8	-6.7	-5.6	-1.1	0	1.1
100	-1.7	-1.1	-1.1	4.4	5.6	6.7
110	-2.2	-2.2	-2.2	2.8	3.9	5.0
120	-3.9	-3.3	-3.3	0.6	1.7	3.3
130	-1.7	-1.1	-1.1	-1.1	3.3	4.4
140	-1.1	-0.6	-0.6	2.8	3.9	4.4
150	-1.1	-0.6	0	2.2	3.3	4.4
160	-0.6	0	0	2.2	3.3	4.4
170	0	0	0	2.2	3.3	4.4
180	0	0.6	0.6	2.2	3.3	4.4

DEPTH (cm)	TEMPERATURE (°C)					
	JUN 29	JUL 5	JUL 15	JUL 27	AUG 6	AUG 10
0	21.1	21.1	20.6	21.1	18.3	18.9
2.5	21.1	21.1	18.9	21.1	17.8	17.8
5	18.9	20.0	16.7	19.4	15.6	14.4
7.5	18.3	18.9	16.7	18.9	15.6	15.0
10	15.6	16.7	13.9	16.1	13.3	12.8
12.5	16.7	17.8	15.6	16.1	15.6	14.4
15	15.6	17.2	15.0	17.8	15.6	14.4
17.5	15.6	17.2	15.0	16.7	15.6	14.4
20	15.6	16.7	14.4	17.2	15.6	13.9
22.5	15.0	16.1	14.4	16.7	15.6	14.4
25	14.4	15.6	14.4	16.7	15.0	13.3
27.5	14.4	15.6	14.4	15.6	15.6	13.9
30	13.9	15.6	14.4	15.6	15.6	13.9
32.5	13.3	15.0	13.9	15.6	15.0	13.3
35	13.3	15.0	14.4	15.6	15.6	14.4
37.5	13.3	14.4	14.4	15.6	15.6	14.4
40	13.3	14.4	13.3	15.6	15.0	13.3
42.5	-	-	-	-	-	-
45	12.8	14.4	13.9	15.6	15.6	13.9
47.5	12.2	14.4	13.9	15.6	15.6	14.4
50	12.2	13.3	13.3	15.6	15.0	13.9
52.5	12.2	13.3	13.3	15.6	15.0	13.9
55	11.1	13.3	13.3	14.4	14.4	13.3
57.5	11.1	12.8	13.3	14.4	14.4	13.9
60	11.1	12.2	13.3	14.4	14.4	13.3
62.5	21.1	21.1	21.1	21.1	-	-
65	-	-	-	-	-	-
67.5	10.0	12.2	13.3	14.4	14.4	13.3
70	10.0	11.1	12.2	13.3	13.3	12.8
72.5	8.3	10.0	10.6	12.2	12.2	11.1
75	9.4	11.1	12.2	13.3	13.3	12.8
77.5	9.4	10.6	12.2	13.3	13.3	12.8
80	9.4	10.6	12.2	13.3	13.3	12.8
82.5	8.9	10.0	11.1	12.2	13.3	12.2
85	7.8	8.3	10.0	10.6	11.1	10.0
87.5	8.9	10.0	11.1	12.2	12.8	12.2
90	2.2	3.3	4.4	5.6	6.7	6.1
100	7.8	8.9	10.6	11.7	12.2	12.2
110	5.6	7.2	8.9	10.0	10.0	10.0
120	3.3	4.4	6.7	7.8	8.3	7.8
130	5.6	6.7	7.8	8.9	10.0	10.0
140	5.6	6.7	8.3	8.9	10.0	10.0
150	5.6	6.7	7.8	8.9	10.0	10.0
160	5.6	6.1	7.8	8.3	9.4	10.0
170	4.4	5.6	7.2	7.8	8.9	8.9
180	4.4	5.6	6.7	7.8	8.9	8.9

DEPTH (cm)	TEMPERATURE (^{o}C)					
	AUG 17	AUG 24	SEP 7	SEP 14	SEP 23	OCT 5
0	20.6	16.7	13.9	16.7	15.6	8.3
2.5	18.9	16.1	13.9	15.6	14.4	7.8
5	16.7	14.4	13.9	12.2	12.2	6.7
7.5	16.7	15.0	12.2	12.2	12.2	7.2
10	14.4	13.3	13.3	10.0	10.0	5.6
12.5	16.1	15.6	11.1	11.1	11.7	7.8
15	16.1	15.6	13.3	11.1	11.1	7.8
17.5	16.7	15.6	13.3	11.7	12.2	8.9
20	15.6	15.6	13.9	11.1	11.1	8.3
22.5	15.6	15.6	13.3	11.1	11.7	8.3
25	15.6	15.6	13.3	10.6	11.1	7.8
27.5	15.6	15.6	13.3	11.1	11.7	8.9
30	15.6	15.6	13.3	11.1	11.7	8.9
32.5	15.0	15.6	13.3	10.6	11.1	8.9
35	15.6	15.6	13.3	11.1	11.7	8.9
37.5	15.0	15.6	13.3	11.1	11.7	9.4
40	15.0	15.0	13.3	10.6	11.1	8.9
42.5	-	-	-	-	-	-
45	15.0	15.6	13.9	11.1	12.2	10.0
47.5	15.0	15.6	14.4	11.1	12.2	10.0
50	14.4	15.0	13.9	11.1	12.2	10.0
52.5	14.4	15.0	13.9	11.1	12.2	10.0
55	14.4	14.4	13.3	11.1	11.7	10.0
57.5	14.4	14.4	13.9	11.1	12.2	10.0
60	13.9	14.4	13.3	11.1	11.7	10.0
62.5	-	21.1	-	-	-	-
65	-	-	-	-	-	-
67.5	13.9	14.4	13.3	11.1	11.7	10.0
70	13.3	13.3	13.3	10.6	11.1	10.0
72.5	11.7	12.2	11.1	8.9	10.0	7.8
75	13.3	13.3	13.3	11.1	11.1	10.0
77.5	13.3	13.3	13.3	11.1	11.1	10.0
80	13.3	13.3	13.3	11.1	11.7	10.0
82.5	12.8	12.8	12.8	10.6	11.1	10.0
85	11.1	11.1	11.1	8.9	9.4	8.3
87.5	12.8	12.8	12.8	11.1	11.1	10.0
90	6.1	6.7	6.7	4.4	4.4	3.9
100	12.2	12.2	12.2	11.1	11.1	10.0
110	10.6	10.0	11.1	10.0	9.4	8.9
120	8.3	8.9	8.9	7.8	7.8	7.2
130	10.0	10.0	11.1	10.0	10.0	10.0
140	10.6	10.0	11.1	10.0	10.0	10.0
150	10.6	10.0	11.1	10.0	10.0	10.0
160	10.0	10.0	11.1	10.0	10.0	10.0
170	9.4	9.4	10.0	9.4	10.0	9.4
180	9.4	9.4	10.0	9.4	10.0	9.4

DEPTH (cm)	TEMPERATURE (°C) 1979 - 1980				
	OCT 12	NOV 19	DEC 13	JAN 3	FEB 5
0	10.0	-0.6	-6.7	-4.4	-5.6
2.5	10.0	-1.1	-2.8	-4.4	-5.6
5	7.8	-2.8	-6.7	-5.6	-6.7
7.5	8.9	-1.7	-5.0	-4.4	-5.6
10	7.2	-3.3	-6.1	-5.6	-6.7
12.5	8.9	-1.1	-3.3	-3.3	-4.4
15	8.9	-1.1	-3.3	-3.3	-5.0
17.5	9.4	-0.6	-2.2	-2.8	-4.4
20	8.9	-0.6	-2.2	-3.3	-4.4
22.5	8.9	0	-2.2	-2.8	-4.4
25	8.9	-0.6	-2.2	-3.3	-4.4
27.5	8.9	0	-2.2	-2.8	-4.4
30	8.9	0	-2.2	-2.8	-3.9
32.5	8.9	0	-2.2	-2.8	-4.4
35	8.9	-0.6	-1.7	-2.2	-3.9
37.5	8.9	0.6	-1.7	-2.2	-3.9
40	8.9	0.6	-1.7	-2.2	-3.9
42.5	-	-	-	-	-
45	9.4	1.1	-1.1	-1.7	-3.3
47.5	9.4	1.7	-1.1	-1.1	-2.8
50	9.4	1.1	-1.1	-1.1	-2.8
52.5	9.4	1.7	-1.1	-1.1	-2.8
55	8.9	1.7	-1.1	-1.1	-2.8
57.5	9.4	0	-0.6	-1.1	-2.2
60	8.9	1.7	-0.6	-1.1	-2.2
62.5	-	-	-	13.3	-
65	-	-	-	-	-
67.5	9.4	2.2	0	-1.1	-2.2
70	8.9	2.2	-0.6	-1.1	-2.2
72.5	7.2	0.6	-1.7	-2.2	-3.3
75	8.9	2.2	0	-1.1	-2.2
77.5	9.4	2.8	0.6	-0.6	-1.7
80	9.4	3.3	0.6	0	-1.1
82.5	8.9	2.8	0	-0.6	-1.7
85	7.8	1.1	-1.1	-1.7	-2.8
87.5	8.9	3.3	0.6	0	-1.1
90	3.3	-2.2	1.7	-2.8	-6.7
100	9.4	3.9	1.7	1.1	-0.6
110	7.8	3.3	1.1	0	-1.1
120	6.7	2.2	0	-1.1	-2.2
130	8.9	4.4	2.2	1.1	0
140	9.4	5.6	3.3	2.2	0.6
150	9.4	5.6	3.3	2.2	1.1
160	9.4	5.6	3.9	2.8	1.1
170	8.9	5.6	3.9	2.8	1.1
180	8.9	6.7	4.4	3.3	2.2

Appendix 3: Depth to groundwater readings in the piezometers and water table well at the Beamer site.

Date	Depth to Groundwater		
	piezometers		water table well
	8m	4m	
May 2, 1978	2.62	2.26	2.29
May 10	2.64	2.29	2.31
May 17	2.64	2.34	2.31
May 24	2.67	2.34	2.29
May 31	2.36	1.68	1.40
June 7	2.49	2.06	1.98
June 17	2.36	2.01	1.96
June 21	2.36	2.01	1.98
June 28	2.34	2.03	2.01
July 5	2.26	2.03	2.01
July 12	2.24	1.96	1.96
July 19	2.26	2.03	2.03
July 26	2.21	1.88	2.01
August 2	2.21	1.85	2.03
August 9	2.29	2.01	2.03
August 16	2.13	1.98	2.01
August 23	1.91	1.85	1.85
August 30	1.91	1.65	2.03
September 13	1.70	1.42	1.27
September 20	1.30	1.24	0.91
September 26	1.73	1.40	1.14
October 4	1.73	1.52	1.22
October 11	1.68	1.45	1.22
October 19	1.60	1.40	1.32
October 26	1.63	1.52	1.35
November 2	1.63	1.52	1.37
November 9	1.83	1.70	1.52
November 17	1.68	1.58	1.42
November 30	1.70	1.73	1.58
December 12	1.83	1.88	1.65
January 29, 1979	2.01	1.98	1.85
February 11	2.13	1.91	1.68
February 27	2.21	2.06	1.93
March 17	2.24	2.03	1.98
April 1	2.26	2.18	-
April 13	2.29	2.16	-
April 27	2.31	2.18	-
May 8	2.34	2.18	-
May 18	2.44	2.49	-
May 25	2.34	2.03	1.52
May 31	2.34	1.93	1.68

Date	Depth to Groundwater		
	piezometers		water table well
	8m	4m	
June 8	2.21	1.91	1.63
June 15	2.24	1.73	1.63
June 23	2.18	1.88	1.68
June 29	2.16	1.88	1.73
July 5	2.06	1.73	1.60
July 15	2.01	1.73	1.45
July 20	1.98	1.73	1.55
July 27	1.85	1.73	1.65
August 6	1.83	1.73	1.68
August 10	1.88	1.83	1.68
August 17	1.91	1.83	1.63
August 24	1.85	1.85	1.73
September 7	1.83	1.85	1.83
September 14	1.73	1.85	1.83
September 21	1.73	1.83	1.83
October 5	1.75	1.91	1.91
October 12	1.83	1.91	1.88
October 19	1.70	1.83	1.88
November 19	1.96	2.13	2.03
December 13	2.03	2.21	2.24
January 3, 1980	2.18	2.24	2.18
February 5	2.36	2.46	2.24

Appendix 4: Depth to groundwater readings in the piezometers and water table well at the Paulencu site.

Date	Depth to Groundwater		
	piezometers		water table well
	6m	4m	
May 2, 1978	2.51	2.46	2.49
May 10	2.46	2.44	2.57
May 17	2.54	2.49	2.52
May 24	2.49	2.46	2.49
May 31	2.52	2.49	2.34
June 7	2.44	2.36	2.36
June 14	2.34	2.31	2.34
June 21	2.36	2.29	2.34
June 28	2.31	2.31	2.31
July 5	2.29	2.31	2.31
July 12	2.21	2.24	2.21
July 19	2.26	2.29	2.26
July 26	2.21	2.21	2.26
August 2	2.18	2.24	2.26
August 9	2.13	2.18	2.21
August 16	2.10	1.13	2.03
August 23	2.03	2.10	2.00
August 30	2.10	2.10	-
September 6	2.03	2.10	2.16
September 13	2.10	2.10	2.13
September 20	2.10	2.10	2.16
September 26	2.03	2.13	2.21
October 4	2.10	2.13	2.21
October 11	2.03	2.10	2.18
October 19	2.10	2.03	1.75
October 26	2.03	2.10	2.18
November 2	2.10	2.13	2.21
November 9	2.21	2.03	2.36
November 16	2.16	2.13	2.52
November 29	2.21	1.27	2.44
December 12	2.26	2.26	2.36
January 29, 1979	2.52	2.46	2.57
February 11	2.46	2.52	2.59
February 27	2.49	2.52	2.54
March 17	2.54	2.52	2.49
April 1	2.57	2.52	2.74
April 13	2.54	2.52	2.59
April 27	2.57	2.54	2.57

Date	Depth to Groundwater		
	piezometers		water table well
	6m	4m	
May 8	2.57	2.57	2.57
May 18	2.57	2.54	2.59
May 25	2.59	2.57	2.59
May 31	2.64	2.49	2.67
June 8	2.57	2.57	2.57
June 15	2.54	2.52	2.52
June 23	2.52	2.46	2.54
June 29	2.54	2.46	2.12
July 5	2.54	2.46	2.52
July 15	2.49	2.44	2.36
July 20	2.34	2.34	2.44
July 27	2.34	2.31	2.44
August 6	2.29	2.29	2.29
August 10	2.29	2.29	2.44
August 17	2.29	2.26	2.29
August 24	2.26	2.24	2.31
September 7	2.18	2.24	2.29
September 14	2.16	2.18	2.34
September 21	2.13	2.06	2.31
October 5	2.16	2.18	2.31
October 12	2.13	2.13	-
October 19	2.06	2.03	2.26
November 19	2.21	2.26	2.44
December 13	2.34	2.31	2.57
January 3, 1980	2.34	2.36	2.52
February 5	2.54	2.54	2.57

Appendix 5: Percent moisture content by volume values using the neutron probe at the Beamer site.

Date	Depth (cm)								
	15	31	46	70	76	91	107	122	137
	%mc by volume								
May 17, 1978	34	36	32	31	33	33	34	37	37
May 24	32	35	31	32	34	34	36	37	37
June 7	38	39	34	33	35	36	35	37	38
June 17	34	37	33	34	35	36	37	38	39
June 21	35	37	36	35	35	36	38	39	36
June 28	32	41	34	34	36	37	38	38	38
July 5	29	33	35	35	36	38	37	39	39
July 12	26	33	35	35	37	37	37	40	40
July 19	31	35	35	36	36	38	38	39	32
August 2	23	28	30	31	31	32	31	32	34
August 9	22	29	30	34	35	37	37	38	40
August 16	24	28	31	34	35	37	36	37	39
August 23	36	38	33	34	34	36	37	37	38
August 31	39	38	33	34	30	37	37	38	39
September 6	39	37	33	33	40	36	37	38	39
September 13	44	40	35	36	37	38	39	39	41
September 20	45	41	35	36	37	38	40	42	-
September 26	47	38	34	34	35	37	36	41	42
October 4	27	20	22	-	-	-	-	-	-
October 11	39	36	32	32	33	33	35	-	-
October 19	29	44	40	38	39	40	40	40	-
October 26	29	42	38	36	37	38	39	40	43
November 2	24	48	47	47	47	47	46	45	45
November 9	30	41	37	34	35	36	36	48	39
November 17	29	39	36	39	35	36	36	38	38
January 29, 1979	17	23	23	21	22	23	23	23	25
February 11	15	20	19	18	19	20	22	24	25
March 17	37	42	39	36	35	35	36	36	39
April 1	34	40	37	35	35	36	35	38	38
April 13	38	40	37	35	35	35	35	38	38
April 27	44	40	37	36	35	36	37	39	40
May 8	32	40	37	35	35	36	36	38	39
May 18	28	40	38	35	35	36	37	39	39
May 25	22	40	38	36	36	37	37	39	39
June 8	19	37	38	35	35	36	36	39	39
June 15	24	35	36	35	35	36	36	38	39
June 23	20	35	35	35	35	36	37	39	38
June 29	16	33	36	35	36	36	37	39	40
July 5	25	36	37	35	35	37	36	39	40

Date	Depth (cm)								
	15	31	46	70	76	91	107	122	137
	%mc by volume								
July 15	32	39	37	35	36	36	37	39	40
July 20	26	39	37	35	35	37	37	39	39
July 27	20	37	37	35	36	37	37	39	39
August 6	21	36	37	35	35	37	37	39	40
August 10	24	36	38	36	36	37	37	40	40
August 17	17	34	37	35	36	37	37	40	39
August 24	15	31	35	35	35	36	36	39	39
September 7	17	30	35	35	35	36	37	38	40
September 14	18	30	35	35	35	35	36	40	40
September 21	15	30	35	34	35	35	35	39	40
October 5	14	29	34	34	35	36	35	38	39
October 12	14	29	34	34	35	35	36	38	39
October 19	14	29	33	33	35	35	35	40	37
November 19	14	27	31	33	33	35	35	38	38
December 13	12	15	20	22	25	27	31	33	33
January 3, 1980	14	22	27	30	33	33	31	35	38
February 5	36	42	42	42	43	43	43	44	45
March 6	32	38	38	38	38	39	39	40	40

Appendix 6: Percent moisture content by volume values using the neutron probe at the Paulencu site.

Date	Depth (cm)								
	15	31	46	70	76	91	107	122	137
	%mc by volume								
May 17, 1978	36	42	43	44	44	45	46	41	33
May 24	31	41	43	43	44	44	45	39	33
June 7	43	45	43	43	45	44	46	41	33
June 14	45	45	43	43	44	44	49	37	32
June 21	44	45	44	44	44	44	46	39	33
June 28	38	47	42	45	46	46	47	40	34
July 5	30	44	45	45	45	45	47	40	33
July 12	30	46	45	45	45	44	47	40	33
July 19	27	42	44	44	45	45	45	40	33
August 2	26	41	45	45	46	46	47	39	36
August 9	24	41	43	43	44	44	45	37	33
August 16	27	45	44	44	45	45	47	38	33
August 23	45	45	44	44	45	44	42	39	33
August 30	42	45	43	43	45	44	46	37	33
September 6	47	46	45	46	45	45	38	34	
September 13	46	44	43	43	44	44	46	35	33
October 4	31	34	30	-	-	-	-	-	-
October 11	49	47	45	46	47	46	45	37	32
October 19	36	41	45	45	46	47	47	48	38
October 26	29	45	43	43	44	45	45	46	37
November 2	16	49	51	53	56	57	54	55	39
November 9	31	44	44	43	44	45	45	47	37
November 16	29	45	43	42	43	45	44	45	36
January 29, 1979	22	46	50	51	52	54	53	54	50
February 11	4	9	15	15	22	29	35	38	42
March 17	38	45	44	43	44	43	35	40	29
April 1	35	45	44	44	43	45	42	47	-
April 13	37	45	45	43	44	45	45	47	-
April 27	49	47	45	44	45	45	47	-	-
May 11	34	27	45	44	44	45	45	48	-
May 18	33	48	47	45	44	45	45	48	-
May 25	25	47	45	45	44	50	45	48	-
June 8	22	44	45	44	44	45	45	47	37
June 15	23	44	45	43	43	46	45	47	37
June 23	23	43	45	44	45	50	46	47	35
June 29	18	39	45	44	44	47	45	47	37
July 5	19	40	45	45	44	46	46	47	37
July 15	30	39	45	45	45	46	45	48	37
July 20	23	43	45	45	44	46	46	48	38
July 27	18	38	45	44	45	47	45	47	37

Date	Depth (cm)								
	15	31	46	70	76	91	107	122	137
	%mc by volume								
August 6	16	31	44	44	45	46	46	47	37
August 10	17	34	44	44	45	46	45	47	36
August 17	15	30	41	44	44	45	45	47	37
August 24	14	29	40	44	45	45	45	47	36
September 7	15	28	37	43	45	45	46	47	37
September 14	16	35	43	43	44	45	45	47	35
September 21	15	42	44	44	45	46	45	47	35
October 5	15	34	41	44	45	47	45	47	36
October 12	14	32	40	43	45	45	47	47	35
October 19	15	31	40	42	44	45	45	47	35
November 19	14	30	38	41	43	45	44	44	35
December 13	14	22	35	38	40	42	42	44	33
January 3, 1980	15	33	38	40	42	42	42	44	45
February 5	37	43	45	45	46	47	47	45	42
March 6	30	37	39	39	40	40	41	38	-

Appendix 7: Soil Solution conductivity readings at the Beamer site.

Date	Depth (cm)				
	31	46	70	76	92
	Soil solution conductivity (mmhos/cm)				
May 17, 1978	34	80	86	96	76
May 24	39	86	92	104	81
May 31	39	88	92	108	86
June 7	48	96	98	112	88
June 17	46	96	98	108	86
June 21	46	97	97	104	87
June 28	47	99	99	108	86
July 5	44	100	100	108	87
July 12	39	98	98	108	88
July 19	39	100	99	108	88
July 26	37	102	100	108	88
August 2	36	100	100	112	87
August 9	34	104	100	108	88
August 16	35	100	98	108	86
August 23	40	100	98	108	85
August 30	45	102	100	108	86
September 6	46	104	100	108	88
September 13	46	102	99	108	88
September 20	48	100	100	108	92
September 26	50	100	100	110	98
October 4	54	104	100	110	96
October 11	53	100	92	108	100
October 19	56	100	100	108	96
November 9	56	110	108	116	-
December 12	11	63	92	100	92
January 29, 1979	30	-	-	-	-
February 11	-	-	38	54	76
March 17	-	42	54	68	88
April 27	57	75	72	91	88
May 8	62	98	92	112	88
May 18	66	108	100	112	92
May 25	-	108	100	112	92
May 31	63	-	102	112	98
June 8	62	104	100	112	94
June 15	59	108	100	112	96

Date	Depth (cm)				
	31	46	70	76	92
	Soil solution conductivity (mmhos/cm)				
July 5	58	112	102	116	96
August 17	56	108	100	116	100
September 14	45	104	100	118	100
October 5	46	112	100	116	98
October 12	45	102	100	112	96
October 19	44	104	96	116	96
November 19	43	104	96	112	96
December 13	42	100	100	120	96
January 3, 1980	20	62	92	112	94
February 5	17	51	70	100	92
March 6	16	24	56	-	82

Appendix 8: Soil solution conductivity readings at the Paulencu site.

Date	Depth (cm)				
	31	46	70	76	92
	Soil solution conductivity (mmhos/cm)				
May 17, 1978	69	86	90	116	104
May 24	72	89	96	124	112
May 31	74	89	98	124	116
June 7	76	91	100	128	116
June 14	77	92	100	100	120
June 21	79	92	100	128	140
June 28	80	92	100	132	120
July 5	79	94	100	132	120
June 12	78	92	102	132	120
July 19	79	93	104	132	124
July 26	76	94	104	124	124
August 2	78	92	104	132	126
August 9	73	94	104	132	124
August 16	76	92	104	132	124
August 23	80	92	102	132	124
August 30	81	93	104	132	124
September 6	82	94	104	132	124
September 13	82	94	102	136	124
September 20	82	95	104	132	126
September 26	82	96	104	136	126
October 4	81	94	102	132	128
October 11	88	108	104	136	124
October 19	80	92	88	120	128
October 26	78	90	104	132	124
November 16	80	92	104	132	124
December 12	-	92	100	132	124
April 27, 1979	67	78	82	100	100
May 8	90	86	88	104	104
May 18	96	104	112	124	106
May 25	94	104	112	132	118
May 31	95	108	112	134	120
June 8	94	104	110	132	120
June 15	94	104	112	136	124
June 23	94	104	112	136	124
July 15	100	108	116	140	128
August 6	-	104	112	140	124
August 10	92	108	116	140	124
August 17	88	108	112	140	128

Date	Depth (cm)				
	31	46	70	76	92
	Soil solution conductivity (mmhos/cm)				
August 24	80	108	112	140	128
September 7	76	108	112	140	128
September 21	86	104	112	140	128
October 5	88	108	112	140	132
October 12	84	104	112	140	124
October 19	84	104	112	140	128
November 19	80	104	108	140	124
December 13	80	100	108	140	124
January 3, 1980	72	100	112	140	128
February 5	32	84	96	140	124
March 6	24	52	84	100	112

Appendix 9: Soluble salt, pH, %mc and EC values for the soil cores taken in 10 cm increments from 0 to 81 cm at the Beamer site.

Date	Soluble Salts						pH	%mc	EC
	Ca^{+2}	Mg^{+2}	Na^{+}	K^{+}	HCO_3^{-}	$SO4^{-2}$			
	(me/100 gm)								(mmhos/cm)
0 - 10 cm									
May 4, 1979	0.2	-	1.5	-	0.5	0.1	5.0	-	0.2
May 11	0.4	0.3	3.0	-	1.4	0.6	4.9	53	0.4
May 18	0.5	0.3	3.1	0.1	1.9	0.1	5.7	47	0.4
May 25	0.8	0.5	3.0	0.1	2.2	0.5	5.5	25	0.5
May 31	0.3	0.3	3.1	-	0.6	0.6	5.0	33	0.4
June 15	0.2	0.2	2.0	0.1	1.3	-	5.5	55	0.3
June 23	0.4	0.4	4.2	0.1	1.3	0.1	-	41	0.5
June 29	0.6	0.6	1.9	0.1	1.0	0.1	4.9	23	0.3
July 6	0.5	0.5	3.1	0.1	2.7	-	5.2	42	0.4
July 15	0.5	0.5	3.7	0.2	1.3	0.6	5.4	35	0.4
July 20	1.2	0.8	2.5	0.2	1.1	0.8	4.9	52	0.3
July 27	0.3	0.2	3.2	-	1.0	0.2	5.4	30	0.3
August 6	0.6	0.5	2.8	0.3	1.3	-	5.2	50	0.3
August 10	1.5	0.8	3.9	0.3	1.9	0.1	5.5	47	0.4
August 17	0.6	0.5	2.6	0.2	1.3	0.1	5.5	19	0.3
August 24	2.5	1.4	3.5	0.5	3.1	2.6	5.6	17	0.7
September 7	1.1	0.9	3.8	0.3	1.0	0.5	4.8	55	0.6
September 14	1.3	1.0	3.8	0.4	1.4	-	4.8	55	0.6
September 21	1.0	0.9	3.5	0.4	1.3	0.6	5.0	21	0.7
October 5	1.7	0.9	2.4	0.4	1.8	0.3	5.3	26	0.5
October 12	0.7	0.7	3.1	0.4	1.2	0.2	5.0	25	0.5
October 19	0.7	0.7	3.3	0.7	1.4	0.8	5.3	29	0.6
November 19	0.5	0.6	4.2	0.2	1.0	0.5	4.9	26	0.6
January 3, 1980	0.4	0.4	3.8	0.1	1.0	0.6	5.2	28	0.5
February 5	0.5	0.7	4.9	0.1	0.5	1.5	4.9	24	0.6
March 6	0.7	0.7	3.8	0.2	1.1	0.4	4.9	25	0.5
10 - 20 cm									
May 4, 1979	0.5	0.9	3.5	0.1	1.3	1.0	6.0	-	0.4
May 11	0.5	0.4	4.4	-	2.4	-	6.3	30	0.6
May 18	0.4	0.4	5.3	-	3.6	0.2	6.7	36	0.6
May 25	0.3	0.3	4.0	-	2.0	0.5	6.0	33	0.5
May 31	0.3	0.3	2.9	-	1.2	0.2	5.6	29	0.3
June 15	0.5	0.8	3.8	0.1	1.8	0.7	6.5	33	0.4
June 23	0.5	1.0	4.2	0.1	1.7	1.1	5.9	26	0.5
June 29	0.5	0.6	3.3	-	1.5	0.4	4.9	24	0.3

Date	Soluble Salts						pH	%mc	EC
	Ca^{+2}	Mg^{+2}	Na^{+}	K^{+}	HCO_3^{-}	SO_4^{-2}			
			(me/100 gm)						(mmhos/cm)
July 6	0.5	1.0	4.1	0.1	1.8	1.0	5.8	24	0.4
July 15	0.5	0.8	4.2	0.2	1.6	0.6	6.1	30	0.4
July 20	0.4	0.5	3.2	-	1.0	0.2	5.5	32	0.3
July 27	0.3	0.3	3.8	0.1	1.4	1.0	6.1	29	0.4
August 6	0.5	0.9	4.0	0.1	1.3	1.8	6.1	23	0.3
August 10	0.5	0.7	5.1	0.1	1.3	2.0	5.4	30	0.5
August 17	0.4	0.8	3.5	0.1	1.0	0.8	5.6	22	0.3
August 24	0.4	0.5	5.0	-	1.6	1.7	5.7	21	0.5
September 7	0.4	0.5	4.7	0.1	1.1	0.5	5.4	26	0.5
September 14	0.1	1.5	4.8	0.1	1.1	1.1	5.2	37	0.5
September 21	0.7	1.2	6.0	0.1	1.4	0.7	5.9	20	0.6
October 5	0.3	0.3	3.3	-	1.1	0.7	6.0	20	0.5
October 12	0.3	0.8	5.2	0.1	1.2	1.1	5.5	19	0.5
October 19	0.4	0.7	5.0	0.1	1.2	1.5	5.8	20	0.5
November 19	0.5	1.5	5.7	0.1	2.0	1.4	6.7	18	0.6
January 3, 1980	0.7	1.7	5.9	0.1	1.7	0.4	6.7	30	0.5
February 5	0.6	1.9	5.6	0.1	1.7	1.0	6.5	19	0.5
March 6	0.4	0.6	5.4	-	1.1	1.5	6.2	18	0.5
20 - 31 cm									
May 4, 1979	0.4	0.4	3.8	-	1.0	2.5	7.2	-	0.6
May 11	0.6	0.4	6.4	-	4.3	0.3	5.8	31	0.9
May 18	0.5	0.4	7.0	-	3.2	0.5	7.6	31	0.8
May 25	0.4	0.4	5.6	-	2.7	2.4	6.8	32	0.7
May 31	0.5	0.9	3.4	-	1.2	0.9	5.9	29	0.3
June 15	0.4	0.5	7.9	-	4.4	0.8	8.0	30	0.9
June 23	0.5	0.8	5.0	-	2.1	1.6	6.2	30	0.6
June 29	0.5	0.7	4.6	-	2.5	2.7	6.1	23	0.6
July 6	0.2	0.2	6.1	-	2.3	4.6	7.2	27	0.7
July 15	0.6	1.0	6.5	0.1	2.9	1.3	7.6	31	0.7
July 20	0.5	0.7	4.7	-	2.3	1.2	6.5	32	0.4
July 27	0.3	0.7	4.9	0.1	1.1	2.0	6.8	27	0.4
August 6	0.4	0.4	6.7	-	3.4	3.4	7.5	23	0.7
August 10	0.3	0.7	5.3	0.1	1.2	2.5	6.6	26	0.5
August 17	0.3	0.4	6.5	-	2.8	3.4	7.7	23	0.7
August 24	0.7	0.7	8.2	0.1	5.4	4.3	7.2	24	0.9
September 7	0.8	1.6	6.7	0.1	2.4	0.8	6.3	21	0.6
September 14	0.5	1.6	7.0	0.1	1.4	1.3	5.9	25	0.7
September 21	0.6	0.6	8.3	0.1	4.3	3.6	7.5	19	0.9
October 5	0.2	0.4	4.1	-	1.0	2.6	6.9	21	0.6
October 12	0.8	0.7	8.5	0.1	4.8	4.2	7.1	19	0.9
October 19	0.6	0.5	7.8	0.1	4.9	4.4	7.3	20	0.8
November 19	0.3	0.8	6.8	0.1	2.0	4.0	7.8	17	0.7
January 3, 1980	0.5	1.2	7.2	0.1	2.5	2.1	7.7	19	0.7
February 5	0.5	1.3	7.0	0.1	2.1	2.6	7.8	18	0.7
March 6	0.7	1.9	7.3	0.1	2.0	1.0	7.8	19	0.6

Date	Soluble Salts						pH	%mc	EC
	Ca^{+2}	Mg^{+2}	Na^{+}	K^{+}	HCO_3^-	SO_4^{-2}			
	(me/100 gm)								(mmhos/cm)
31 - 41 cm									
May 4, 1979	0.3	0.2	5.0	-	1.4	4.0	8.0	-	0.7
May 11	31.4	5.8	7.0	0.2	1.1	39.6	7.5	28	2.8
May 18	10.6	4.1	10.0	0.1	1.8	18.8	7.3	32	2.0
May 25	0.5	0.5	8.7	-	4.4	6.3	7.9	31	1.0
May 31	0.5	0.8	4.8	0.1	1.8	4.2	7.4	26	0.6
June 15	0.9	0.9	8.1	0.1	1.9	8.3	8.1	26	1.3
June 23	0.3	4.0	8.1	-	3.0	11.5	7.9	29	1.0
June 29	0.7	0.6	7.9	-	5.8	6.3	7.3	23	0.9
July 6	0.9	1.0	9.6	0.1	2.3	22.4	7.7	26	1.3
July 13	3.7	2.5	10.9	0.1	1.2	11.5	7.6	27	1.5
July 20	0.3	0.3	6.3	-	3.2	3.7	7.6	27	0.6
July 27	29.9	6.9	10.9	0.1	0.6	45.8	7.2	25	2.8
August 6	28.7	7.3	12.8	0.2	0.5	42.7	7.6	24	2.8
August 10	11.7	4.8	12.0	0.2	0.9	27.1	7.1	23	2.0
August 17	0.2	0.3	7.0	-	2.6	8.9	8.0	25	0.7
August 24	21.2	6.3	11.7	0.2	2.2	38.5	6.9	24	2.5
September 7	0.5	0.5	8.3	-	4.5	6.2	7.8	20	0.9
September 14	17.2	6.1	17.0	0.2	1.6	39.6	6.9	31	2.7
September 21	35.0	6.8	13.7	0.2	1.7	68.7	7.1	18	2.7
October 5	0.4	0.6	8.7	0.1	2.9	10.4	7.7	23	0.8
October 12	47.4	7.0	10.7	0.1	2.2	65.6	6.6	19	3.4
October 19	15.0	5.1	11.7	0.2	2.0	30.2	7.1	22	2.3
November 19	30.0	6.7	13.7	0.2	0.5	56.2	7.6	18	3.3
January 3, 1980	0.6	0.6	9.8	0.1	1.4	5.2	8.1	19	1.0
February 5	23.7	5.4	10.9	0.2	0.9	49.0	7.9	18	2.3
March 6	0.3	0.3	7.4	-	1.6	6.3	8.4	21	0.8
41 - 51 cm									
May 4, 1979	0.4	0.1	5.8	0.1	1.3	5.2	8.6	-	0.7
May 11	31.4	5.8	7.0	0.2	1.1	39.6	7.5	28	2.8
May 18	19.0	4.8	8.3	0.2	0.9	29.2	7.6	29	2.5
May 25	1.4	1.4	11.1	0.1	2.6	10.4	8.2	26	1.4
May 31	1.6	1.2	10.0	0.1	1.5	8.3	7.7	25	1.3
June 15	4.9	2.9	11.1	0.1	0.8	16.7	8.0	25	1.9
June 23	0.5	0.5	8.3	-	3.4	8.3	7.6	28	1.0
June 29	2.8	1.8	7.6	0.1	5.6	20.8	6.8	24	1.3
July 6	13.0	5.0	12.0	0.2	1.1	42.0	8.0	23	2.2
July 15	14.7	5.2	11.7	0.1	0.8	26.0	8.0	26	2.2
July 20	18.6	6.2	11.7	0.1	0.5	28.1	7.5	26	2.3
July 27	13.7	4.8	10.4	0.2	0.7	29.2	7.5	26	2.0
August 6	13.5	5.6	12.8	0.2	0.9	34.9	7.8	25	2.2
August 10	14.7	5.0	10.9	0.2	0.9	28.1	7.4	25	2.1
August 17	6.0	3.4	13.5	0.1	0.8	21.4	7.8	24	1.9

Date	Soluble Salts						pH	%mc	EC
	Ca^{+2}	Mg^{+2}	Na^{+}	K^{+}	HCO_3^{-}	SO_4^{-2}			
	(me/100 gm)								(mmhos/cm)
August 24	16.1	4.8	10.4	0.2	1.4	30.2	7.6	24	2.2
September 7	0.5	0.5	8.5	0.1	4.0	9.9	8.0	20	0.9
September 14	15.0	5.3	16.1	0.2	1.0	34.3	7.6	29	2.6
September 21	20.0	5.7	13.9	0.2	1.3	36.0	7.5	14	2.7
October 5	3.5	0.7	14.4	-	0.3	57.3	7.5	23	3.4
October 12	17.5	5.5	13.7	0.2	1.1	34.4	7.3	21	2.6
October 19	15.7	5.3	13.7	0.2	1.2	35.4	7.5	19	2.5
November 19	30.0	6.7	13.7	0.2	0.5	56.2	7.6	18	3.3
January 3, 1980	23.7	5.4	12.0	0.2	0.4	49.0	8.0	19	2.3
February 5	15.0	4.0	9.8	0.2	0.5	34.4	7.9	19	2.1
March 6	13.5	4.6	10.9	0.2	0.7	35.4	8.0	20	2.2
51 - 61 cm									
May 4, 1979	10.6	3.6	13.5	0.1	0.5	25.0	8.2	-	2.5
May 11	27.0	5.0	7.0	0.2	0.2	35.4	7.7	26	2.5
May 18	19.0	4.8	8.3	0.2	0.9	29.2	7.6	29	2.5
May 25	30.4	6.6	14.4	0.2	1.1	51.6	8.1	27	3.3
May 31	31.4	5.8	12.4	0.2	1.0	35.4	7.6	25	3.3
June 15	2.1	1.3	9.6	0.1	0.9	11.5	8.1	25	1.6
June 23	0.2	0.2	6.3	-	2.4	3.6	8.3	25	0.8
June 29	14.4	5.2	10.0	0.1	2.5	37.5	7.0	23	2.2
July 6	14.3	4.8	12.0	0.2	0.9	43.2	8.1	25	2.8
July 15	13.7	4.4	10.0	0.2	0.6	20.8	8.0	26	2.1
July 20	3.8	2.5	11.3	0.1	0.8	12.5	7.9	25	1.5
July 27	15.7	4.9	10.0	0.2	0.7	28.1	7.5	26	2.1
August 6	15.0	6.2	14.3	0.2	0.5	38.5	7.8	25	2.4
August 10	17.5	4.8	10.4	0.2	0.5	34.9	7.4	26	2.2
August 17	16.3	5.6	12.0	0.2	0.6	35.9	7.8	24	1.8
August 24	17.0	4.6	10.4	0.2	1.1	32.3	7.8	25	2.2
September 7	17.5	5.4	13.9	0.2	1.6	35.4	7.7	21	2.5
September 14	15.7	6.6	20.4	0.3	1.2	45.8	7.5	31	3.0
September 21	16.0	5.1	14.8	0.2	1.1	35.4	7.9	20	2.5
October 5	32.4	7.6	14.8	0.2	1.0	63.5	7.7	24	3.4
October 12	5.0	2.9	14.4	0.2	0.9	20.3	7.9	20	2.0
October 19	25.0	6.3	16.1	0.2	0.8	50.0	7.8	20	3.1
November 19	10.7	4.0	14.8	0.2	0.5	28.1	8.0	19	2.3
January 3, 1980	23.7	5.1	13.1	0.2	0.4	50.0	8.0	19	2.4
February 5	15.0	3.8	9.8	0.2	0.5	33.3	8.0	19	2.0
March 6	0.2	0.2	6.5	0.1	1.5	4.2	8.6	19	0.9
61 - 71 cm									
May 4, 1979	13.6	4.2	14.1	0.1	0.6	28.1	8.3	-	2.8
May 11	16.5	4.2	6.9	0.2	1.2	24.0	7.7	26	2.1

Date	Soluble Salts						pH	%mc	EC
	Ca^{+2}	Mg^{+2}	Na^{+}	K^{+}	HCO_3^{-}	SO_4^{-2}			
	(me/100 gm)								(mmhos/cm)
May 18	13.7	3.6	8.3	0.2	0.2	21.9	7.6	29	2.1
May 25	17.5	5.4	14.6	0.2	0.8	41.4	7.8	27	3.0
May 31	25.0	5.7	11.7	0.2	0.8	40.1	7.7	24	3.3
June 15	12.8	4.2	10.4	0.2	0.6	31.3	8.0	25	2.8
June 23	0.3	0.3	6.4	-	3.1	7.3	7.9	27	0.8
June 29	14.6	5.1	10.9	0.1	2.1	41.7	7.3	24	2.2
July 6	15.2	4.7	11.3	0.2	0.8	42.7	8.0	25	2.2
July 15	13.8	4.2	9.1	0.2	0.6	22.9	8.0	26	2.0
July 20	24.4	6.7	12.8	0.1	0.5	34.4	8.0	25	2.6
July 27	16.0	4.5	9.1	0.2	0.7	27.1	7.4	26	2.1
August 6	13.7	5.7	14.3	0.2	0.6	35.4	7.8	25	2.4
August 10	24.9	5.6	10.4	0.2	0.5	40.6	7.4	25	2.8
August 17	16.5	5.1	12.4	0.2	0.5	32.3	7.9	24	2.5
August 24	16.8	4.8	10.2	0.2	1.4	30.2	7.6	25	2.2
September 7	15.5	4.7	14.4	0.2	1.0	36.4	7.9	22	2.5
September 14	22.4	8.2	24.8	0.3	0.6	59.4	7.6	33	3.6
September 21	22.4	5.8	16.1	0.2	0.8	45.8	7.9	26	2.9
October 5	15.0	5.5	14.6	0.2	0.8	32.8	7.6	24	3.4
October 12	2.8	1.9	13.7	0.1	1.1	15.6	8.0	21	1.7
October 19	20.0	5.8	16.1	0.2	0.7	42.7	7.7	21	2.9
November 19	6.0	3.1	15.2	0.2	0.7	23.4	8.0	20	2.1
January 3, 1980	17.5	4.1	13.1	0.2	0.5	37.5	8.0	20	2.2
February 5	20.0	4.8	13.1	0.2	0.9	46.9	8.0	19	2.4

71 - 81 cm

May 4, 1979	14.6	4.3	14.8	0.1	0.5	31.2	8.6	-	2.8
May 11	14.6	3.7	8.0	0.2	0.9	21.9	7.6	27	2.2
May 18	14.6	4.0	9.6	0.2	0.5	22.9	7.6	27	2.3
May 25	1.0	0.8	10.4	0.1	1.2	9.4	8.1	24	1.4
May 31	15.3	5.0	11.0	0.2	0.5	30.2	8.1	24	2.8
June 15	14.0	4.0	10.9	0.2	0.6	31.3	8.0	25	2.8
June 23	0.7	0.6	8.6	0.1	1.7	6.3	8.1	27	1.1
June 19	14.6	4.7	10.7	0.1	1.4	40.0	7.6	24	2.2
July 6	16.2	4.7	9.6	0.2	0.8	43.2	7.9	25	2.2
July 15	16.2	4.5	10.0	0.2	0.7	25.0	7.9	26	2.1
July 20	17.2	5.7	12.8	0.1	0.3	27.6	8.0	25	2.4
July 27	31.2	5.9	10.1	0.3	0.5	47.4	7.5	25	2.6
August 6	13.8	5.5	13.0	0.2	0.5	35.4	7.8	24	2.4
August 10	15.2	4.3	10.6	0.2	0.6	29.2	7.4	26	2.1
August 17	10.2	3.9	13.3	0.2	0.5	26.5	7.8	25	2.2
August 24	5.0	1.4	2.6	0.2	1.1	32.3	7.6	24	2.2
September 7	14.5	4.6	17.8	0.2	0.7	32.3	7.9	23	2.5
September 14	31.2	8.2	23.7	0.3	0.9	62.5	7.5	32	3.7
September 21	30.0	6.5	17.0	0.2	1.1	53.1	7.6	21	3.2
October 5	30.0	7.1	15.7	0.2	0.6	52.1	7.8	24	2.3

Date	Soluble Salts						pH	%mc	EC
	Ca^{+2}	Mg^{+2}	Na^{+}	K^{+}	HCO_3^{-}	SO_4^{-2}			
	(me/100 gm)								(mmhos/cm)
October 12	18.5	5.6	17.0	0.2	0.5	45.8	7.9	22	2.9
October 19	22.4	6.0	17.0	0.2	0.7	48.9	7.6	22	2.9
November 19	16.1	5.1	17.0	0.2	0.4	38.5	7.8	22	2.7
January 3, 1980	18.7	4.5	14.1	0.2	0.5	45.8	8.0	21	2.3
February 5	0.2	0.2	7.6	-	1.3	5.2	8.5	21	0.9

Appendix 10: Soluble salt, pH, %mc and EC values for the soil cores taken in 10 cm increments from 0 to 81 cm at the Paulencu site.

Date	Soluble Salts						pH	%mc	EC
	Ca^{+2}	Mg^{+2}	Na^{+}	K^{+}	HCO_3^{-}	SO_4^{-2}			
	(me/100 gm)								(mmhos/cm)
0 - 10 cm									
May 4 1979	0.7	0.4	2.0	0.1	0.6	1.4	6.0	-	0.3
May 11	0.6	0.3	3.3	0.1	1.0	0.1	4.8	53	0.5
May 18	0.4	0.4	4.4	0.1	0.9	0.1	5.3	47	0.6
May 25	0.2	0.2	1.7	0.1	1.2	0.8	5.3	35	0.5
May 31	0.2	0.3	4.0	0.1	1.1	1.0	5.1	56	0.6
June 15	0.3	0.2	3.4	0.1	0.9	2.9	5.4	36	0.4
June 23	0.3	0.3	3.1	0.1	1.2	1.0	5.3	34	0.4
June 29	0.7	0.9	4.7	0.1	1.7	1.7	5.3	22	0.6
July 6	0.2	0.2	2.8	-	0.9	1.0	4.9	25	0.4
July 15	2.0	1.4	4.3	0.1	0.9	2.3	4.8	48	0.8
July 20	0.3	0.3	3.6	0.1	0.9	0.6	4.7	33	0.4
July 27	1.1	1.0	5.4	0.1	0.9	6.5	5.6	20	0.7
August 6	0.5	0.5	3.2	0.2	0.8	1.6	5.0	29	0.4
August 10	0.9	0.5	3.3	0.2	0.9	2.8	5.7	43	0.6
August 17	0.4	0.3	3.7	0.1	0.7	2.6	5.2	14	0.4
August 24	0.6	0.7	5.6	0.2	1.3	1.5	5.0	16	0.7
September 7	1.2	1.1	4.4	0.4	1.4	3.3	4.7	35	0.7
September 14	1.0	0.7	3.7	0.3	1.3	0.7	4.9	42	0.7
September 21	1.0	0.9	4.2	0.5	1.2	1.0	4.9	17	0.7
October 5	0.9	0.9	4.4	0.5	1.2	0.6	4.9	28	0.7
October 12	0.5	0.5	3.8	0.2	1.0	0.7	4.8	21	0.6
October 19	0.5	0.5	4.1	0.2	0.9	1.9	5.2	20	0.7
November 16	0.4	0.5	3.8	0.2	0.8	2.8	4.8	21	0.6
January 3, 1980	7.7	3.4	7.8	0.2	0.7	0.8	5.5	40	1.4
February 5	017	0.7	5.7	0.1	0.1	2.6	4.3	37	0.1
March 6	0.6	1.2	9.1	0.1	0.1	0.4	5.2	40	1.1
10 - 20 cm									
May 4, 1979	0.4	0.2	4.0	-	0.9	3.3	6.7	-	0.6
May 11	0.4	0.2	4.1	-	1.2	-	5.7	40	0.6
May 18	0.3	0.3	4.8	-	1.2	0.1	5.6	39	0.6
May 25	0.6	1.4	5.1	0.1	1.3	1.0	6.0	40	0.5
May 31	0.5	1.2	4.6	0.1	1.5	1.0	5.8	36	0.5
June 15	0.5	1.2	5.7	0.1	1.1	1.5	6.4	33	0.7
June 23	0.8	1.7	5.0	0.1	1.8	1.0	5.9	33	0.5
June 29	0.7	1.6	5.2	0.1	2.0	1.3	6.1	23	0.6

Date	Soluble Salts						pH	%mc	EC
	Ca^{+2}	Mg^{+2}	Na^{+}	K^{+}	HCO_3^{-}	SO_4^{-2}			
			(me/100 gm)						(mmhos/cm)
July 6	0.4	0.8	5.0	0.1	1.7	2.2	5.9	26	0.6
July 15	0.4	0.9	4.9	0.1	1.0	1.1	5.8	32	0.5
July 20	0.3	0.7	3.7	0.1	0.9	0.7	5.5	31	0.3
July 27	0.7	1.5	5.4	0.1	1.0	1.6	6.3	22	0.6
August 6	0.3	0.5	4.9	0.1	0.8	3.2	5.5	20	0.6
August 10	0.3	0.4	6.3	0.1	0.9	2.7	5.1	38	0.7
August 17	0.3	0.5	5.4	0.1	0.9	2.0	5.6	18	0.5
August 24	1.5	2.2	10.0	0.2	1.6	1.6	5.9	22	1.1
September 7	0.6	1.0	6.7	0.1	1.0	1.8	5.4	18	0.7
September 14	0.6	0.9	4.9	0.1	1.1	0.8	6.2	23	0.5
September 21	0.7	1.2	6.7	0.1	1.2	1.4	5.3	22	0.7
October 5	0.4	0.7	6.0	0.1	1.0	2.8	5.3	23	0.7
October 12	0.3	0.5	5.4	-	0.9	1.8	5.6	21	0.6
October 19	0.5	1.3	5.6	0.1	0.9	1.5	6.1	21	0.6
November 16	0.3	0.5	6.1	0.1	1.0	2.2	5.9	24	0.7
January 3, 1980	0.7	1.6	5.5	0.1	0.9	1.3	6.1	22	0.5
March 6	6.2	4.4	13.7	0.2	0.8	9.6	7.0	38	2.1

20 - 31 cm

May 4, 1979	0.3	0.1	3.8	-	0.7	3.3	7.5	-	0.6
May 11	0.4	0.2	5.9	-	1.7	0.2	6.5	34	0.7
May 18	0.3	0.4	5.5	-	1.5	2.9	6.4	31	0.6
May 25	0.5	1.0	5.8	0.1	1.5	1.2	6.1	32	0.6
May 31	0.5	1.4	5.6	0.1	1.6	0.9	6.6	35	0.6
June 15	0.5	0.7	6.0	0.2	0.6	5.2	7.3	32	0.7
June 23	0.4	1.0	6.0	0.1	1.8	3.7	6.7	30	0.7
June 29	0.4	1.2	6.5	0.1	2.0	1.9	6.9	26	0.7
July 6	0.5	1.7	8.9	0.1	2.9	1.1	6.7	32	0.9
July 15	0.4	0.9	5.9	0.1	1.2	1.0	6.7	35	0.6
July 20	0.5	1.7	6.6	0.1	1.4	1.1	6.5	34	0.6
July 27	0.3	0.6	5.7	0.1	0.8	3.2	6.8	27	0.6
August 6	0.6	1.7	8.9	0.1	1.8	1.6	6.5	32	0.8
August 10	0.4	0.6	6.7	0.1	0.9	2.2	6.1	31	0.7
August 17	0.2	0.4	6.3	0.1	0.7	3.8	6.4	16	0.6
August 24	0.4	0.7	6.3	0.1	1.8	2.3	6.4	16	0.7
September 7	0.7	2.4	7.7	0.2	1.0	0.9	6.7	19	0.7
September 14	0.7	1.3	6.5	0.1	2.4	1.4	7.1	22	0.6
September 21	0.8	2.0	8.2	0.1	1.2	1.0	6.1	22	0.8
October 5	0.4	1.0	5.9	0.1	1.0	1.8	6.0	21	0.6
October 12	0.3	0.4	6.9	0.1	0.9	3.1	5.9	23	0.7
October 19	0.3	0.7	6.5	0.1	1.0	2.7	6.8	21	0.7
November 16	0.3	0.7	8.2	0.1	1.2	2.7	6.9	29	0.9
January 3, 1980	0.6	1.9	6.4	0.1	1.0	1.5	7.1	22	0.6
March 6	12.5	5.6	10.4	0.2	0.6	5.0	7.3	38	2.3

Date	Soluble Salts						pH	%mc	EC
	Ca^{+2}	Mg^{+2}	Na^{+}	K^{+}	HCO_3^{-}	SO_4^{-2}			
	(me/100 gm)								(mmhos/cm)
31 - 41 cm									
May 4, 1979	0.3	0.2	5.0	-	1.4	4.0	8.0	-	0.7
May 11	0.4	0.4	6.7	0.1	1.6	5.2	6.9	35	0.8
May 18	0.6	0.6	7.2	0.1	2.1	12.5	6.4	31	0.9
May 25	0.6	3.1	8.7	0.2	1.1	16.7	6.7	33	0.9
May 31	0.5	1.6	6.0	0.2	1.3	6.2	7.3	36	0.7
June 15	14.7	4.7	10.9	0.2	0.6	36.5	7.8	28	2.8
June 23	0.2	0.4	8.3	0.1	1.6	14.6	7.1	34	0.9
June 29	20.5	6.7	15.7	0.2	1.3	62.5	6.9	32	3.3
July 6	0.2	0.3	7.8	-	1.7	5.5	7.2	29	1.0
July 15	0.4	0.9	6.5	0.1	1.6	7.3	7.5	35	0.6
July 20	24.9	7.6	15.4	0.2	1.5	35.4	7.1	31	2.9
July 27	17.3	5.8	13.0	0.2	0.8	39.6	7.1	30	2.4
August 6	17.2	5.8	115.	0.2	1.5	34.4	6.6	27	2.2
August 10	0.3	1.0	9.6	0.1	1.0	17.2	6.7	34	0.9
August 17	0.6	3.9	13.5	0.1	1.4	2.4	6.6	22	2.0
August 24	6.2	4.0	16.3	0.2	1.5	23.9	6.7	24	2.1
September 14	30.0	6.9	14.3	0.2	1.1	54.7	7.6	23	3.1
September 21	0.7	2.0	9.8	0.1	1.6	20.8	6.7	23	0.9
October 5	0.3	0.6	7.4	0.1	1.0	6.2	6.3	25	0.7
October 12	27.5	8.2	18.7	0.3	0.4	59.9	6.3	29	3.3
October 19	0.7	1.0	10.4	0.1	1.5	12.5	6.7	24	1.3
November 16	13.7	6.1	16.1	0.2	0.7	40.6	7.2	32	2.4
January 3, 1980	10.5	0.7	9.8	0.1	0.7	12.5	7.2	32	1.2
March 6	12.7	5.8	16.3	0.2	0.6	46.9	7.5	35	2.3
41 - 51 cm									
May 4, 1979	0.4	0.1	5.8	0.1	1.3	5.2	8.6	-	0.9
May 11	19.0	6.0	15.2	0.2	0.9	34.4	7.3	37	2.8
May 18	0.3	0.5	7.4	-	1.6	9.4	7.1	29	0.8
May 25	11.1	5.0	17.4	0.2	0.9	34.4	6.7	33	2.6
May 31	0.4	0.5	8.3	0.1	1.7	9.4	7.5	36	1.0
June 15	13.4	5.0	11.1	0.2	0.3	34.4	7.9	31	2.8
June 23	0.3	0.8	7.4	0.1	2.6	13.5	7.4	35	1.0
June 29	10.6	5.0	15.9	0.2	1.2	44.8	7.7	33	2.8
July 6	0.3	0.5	11.1	0.1	2.9	9.4	7.8	30	1.2
July 15	8.2	4.1	13.7	0.2	1.0	20.8	7.5	36	2.0
July 20	18.5	6.7	15.6	0.2	0.6	30.7	7.6	30	2.5
July 27	13.2	4.9	12.6	0.2	0.6	31.3	7.4	30	2.1
August 6	18.2	5.7	12.6	0.2	0.6	40.6	7.1	24	2.3
August 10	34.9	8.6	18.7	0.2	0.9	60.4	7.0	38	3.6
August 17	29.9	8.6	18.9	0.3	0.4	56.3	7.5	28	3.5
August 24	16.7	6.4	20.0	0.2	1.1	44.8	7.5	29	2.9

Date	Soluble Salts						pH	%mc	EC
	Ca^{+2}	Mg^{+2}	Na^{+}	K^{+}	HCO_3^{-}	SO_4^{-2}			
	(me/100 gm)								(mmhos/cm)
September 14	15.2	5.0	13.5	0.2	1.4	32.3	7.8	24	2.2
September 21	1.6	1.6	15.2	0.1	2.2	13.0	7.3	27	1.7
October 5	0.2	0.5	9.1	0.1	0.9	18.7	6.6	27	1.0
October 12	17.5	7.4	19.6	0.3	0.9	45.8	7.2	33	3.0
October 19	4.0	3.5	17.4	0.2	1.0	22.9	7.4	28	2.1
November 16	14.7	6.8	19.6	0.3	0.6	46.8	7.7	33	2.8
January 3, 1980	13.2	5.6	10.4	0.2	0.8	40.6	7.6	32	2.3
March 6	12.5	6.1	17.4	0.2	0.7	43.8	7.6	34	2.4
51 - 61 cm									
May 4, 1979	10.6	3.6	13.5	0.1	0.5	25.0	8.2	-	2.6
May 11	32.9	7.2	16.1	-	1.0	50.0	7.2	38	3.4
May 18	0.3	0.4	6.2	-	1.6	7.3	6.5	33	0.8
May 25	16.7	5.8	18.9	0.3	0.9	46.9	7.5	33	3.1
May 31	4.2	2.5	10.4	0.2	1.4	15.6	7.6	37	1.9
June 15	13.0	4.9	13.5	0.1	0.5	36.5	7.9	31	2.8
June 23	0.3	0.5	10.4	0.1	2.7	7.3	7.9	31	1.3
June 29	11.5	5.6	18.3	0.2	1.1	55.2	7.7	33	3.3
July 6	13.0	5.8	18.3	0.2	1.0	41.2	7.7	31	3.3
July 15	15.2	6.2	16.7	0.2	0.9	29.2	7.5	36	2.5
July 20	6.1	3.8	16.1	0.2	0.7	20.3	7.8	30	2.1
July 27	26.2	7.9	17.8	0.2	0.5	55.7	7.5	31	3.1
August 6	13.6	5.7	16.5	0.2	1.5	35.9	7.4	29	2.4
August 10	16.0	5.8	17.2	0.2	0.5	35.9	7.3	25	2.8
August 17	5.9	4.0	20.4	0.2	1.4	27.1	7.7	30	2.4
August 24	16.5	6.5	21.5	0.3	1.0	43.7	7.5	31	3.2
September 14	17.5	5.4	15.2	0.2	0.7	36.0	8.0	24	2.7
September 21	1.0	4.6	18.3	0.2	1.4	31.3	7.5	28	2.5
October 5	0.2	0.5	9.8	0.1	1.4	13.0	7.5	30	1.1
October 12	22.5	7.8	20.4	0.3	0.7	54.7	7.5	25	3.2
October 19	5.0	3.7	17.4	0.2	0.7	28.1	7.6	30	2.4
November 16	22.4	9.5	25.2	0.3	0.4	70.8	7.5	35	3.6
January 3, 1980	14.2	6.1	15.2	0.2	0.6	50.0	7.7	33	2.5
March 6	12.5	6.3	18.5	0.2	0.7	47.9	7.7	37	2.5
61 - 71 cm									
May 4, 1979	13.8	4.7	14.1	0.2	0.1	27.6	7.1	-	2.6
May 11	32.9	72.0	16.1	-	1.0	50.0	7.2	38	2.6
May 18	0.3	0.5	10.0	0.1	2.9	15.6	7.7	33	1.1
May 25	16.5	6.0	17.8	0.2	1.2	42.7	7.3	33	3.1
May 31	0.8	0.7	9.0	0.1	1.7	7.3	7.7	36	1.2
June 15	14.1	5.3	15.4	0.2	0.5	41.7	7.8	32	2.8
June 23	0.3	0.5	8.1	0.1	3.4	8.3	7.7	35	1.3
June 29	13.0	6.2	19.6	0.2	1.1	58.3	7.7	33	3.3
July 6	15.2	5.8	18.3	0.2	2.2	42.1	7.8	30	2.2
July 15	8.7	4.9	19.1	0.2	0.4	25.5	7.7	37	2.4

Date	Soluble Salts						pH	%mc	EC
	Ca^{+2}	Mg^{+2}	Na^{+}	K^{+}	HCO_3^{-}	SO_4^{-2}			
	(me/100 gm)								(mmhos/cm)
July 20	18.0	7.2	18.5	0.2	0.7	40.1	7.8	30	2.9
July 27	14.1	5.8	17.4	0.2	0.6	41.7	7.5	30	2.5
August 6	14.6	6.1	17.4	0.3	0.4	39.1	7.3	29	2.8
August 10	14.5	5.6	18.9	0.2	1.2	41.7	7.5	33	2.8
August 17	0.6	1.0	16.1	0.1	1.6	14.6	7.9	32	1.8
August 24	13.6	6.3	24.1	0.3	0.9	43.2	7.5	33	3.2
September 14	15.8	5.2	14.8	0.2	0.6	36.4	8.0	23	2.5
September 21	0.5	3.3	19.1	0.2	1.3	25.5	7.8	30	2.2
October 5	0.3	0.7	13.7	0.1	2.4	8.8	8.0	31	1.5
October 12	29.9	2.1	23.7	0.3	0.7	69.8	7.6	31	3.7
October 19	4.0	3.6	20.4	0.2	0.8	27.0	7.6	32	2.4
January 3, 1980	13.0	6.2	17.4	0.2	0.5	50.4	7.8	34	2.5
March 6	25.0	7.4	21.8	0.3	0.4	67.7	7.8	35	3.2

71 - 81 cm

May 4, 1979	13.8	5.1	16.1	0.2	-	27.6	7.0	-	3.0
May 11	11.0	4.4	15.9	0.2	1.0	25.5	7.6	37	2.2
May 18	8.1	4.1	14.8	0.2	1.4	26.0	7.1	32	2.4
May 25	13.8	5.8	20.7	0.3	0.7	41.7	7.6	34	3.1
May 31	4.0	2.1	12.4	0.2	1.1	15.1	7.5	36	1.9
June 15	13.1	5.8	19.8	0.3	0.6	40.0	7.9	33	2.8
June 23	4.5	3.3	16.3	0.2	1.2	24.5	7.7	36	2.2
June 29	14.5	5.8	18.7	0.2	1.3	55.2	7.7	33	3.3
Juny 6	2.1	1.9	16.5	0.1	1.3	17.7	7.9	33	2.2
July 15	0.7	1.2	14.8	0.1	1.3	11.5	7.8	38	1.8
July 20	13.2	5.9	18.7	0.2	0.5	38.5	7.8	30	2.8
July 27	1.2	1.5	15.6	0.1	1.1	18.2	7.7	35	1.8
August 6	15.2	6.0	17.2	0.2	0.6	40.6	7.5	37	2.7
August 10	8.2	5.0	22.6	0.2	0.6	35.9	7.5	35	2.8
August 17	0.6	1.1	17.0	0.1	0.9	13.5	7.7	33	1.8
August 24	14.7	7.1	25.9	0.3	1.0	50.0	7.5	36	3.3
September 14	27.4	6.5	17.0	0.2	0.7	54.1	7.9	24	3.2
September 21	22.4	7.4	24.4	0.3	0.7	53.1	7.6	32	3.3
October 5	0.4	0.8	13.7	0.1	2.4	8.8	7.8	33	1.4
October 12	20.0	8.2	23.7	0.3	0.3	58.3	7.4	31	3.6
October 19	15.0	8.0	24.8	0.3	0.7	55.2	7.4	35	3.5
January 3, 1980	17.2	7.4	18.5	0.3	0.5	61.5	7.8	35	3.0
March 6	17.5	5.8	22.8	0.3	0.5	56.3	7.8	36	3.0

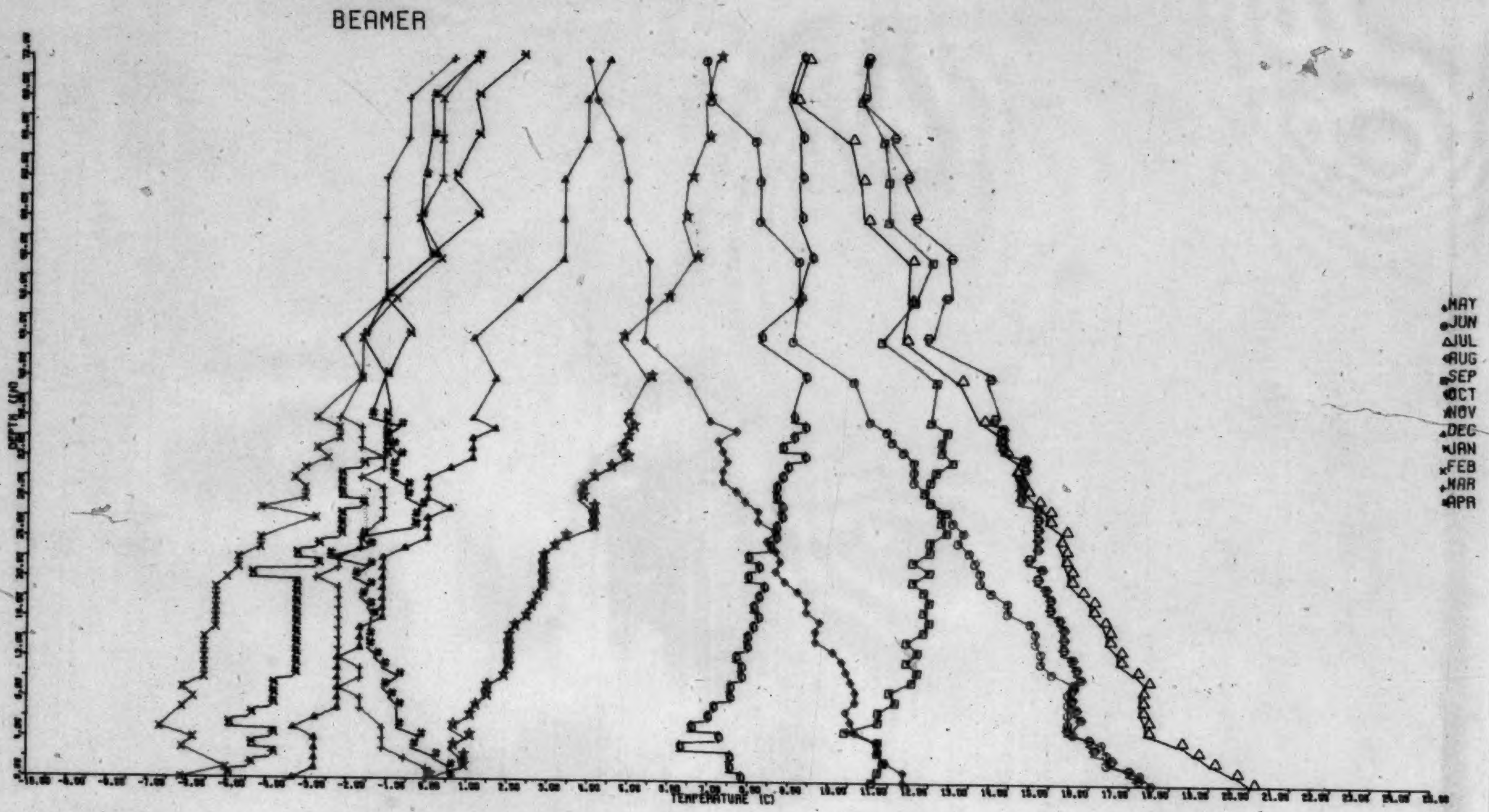

Figure 5: Average monthly soil temperatures in $^{\circ}C$ at the Beamer site from May 1978 to April 1979.

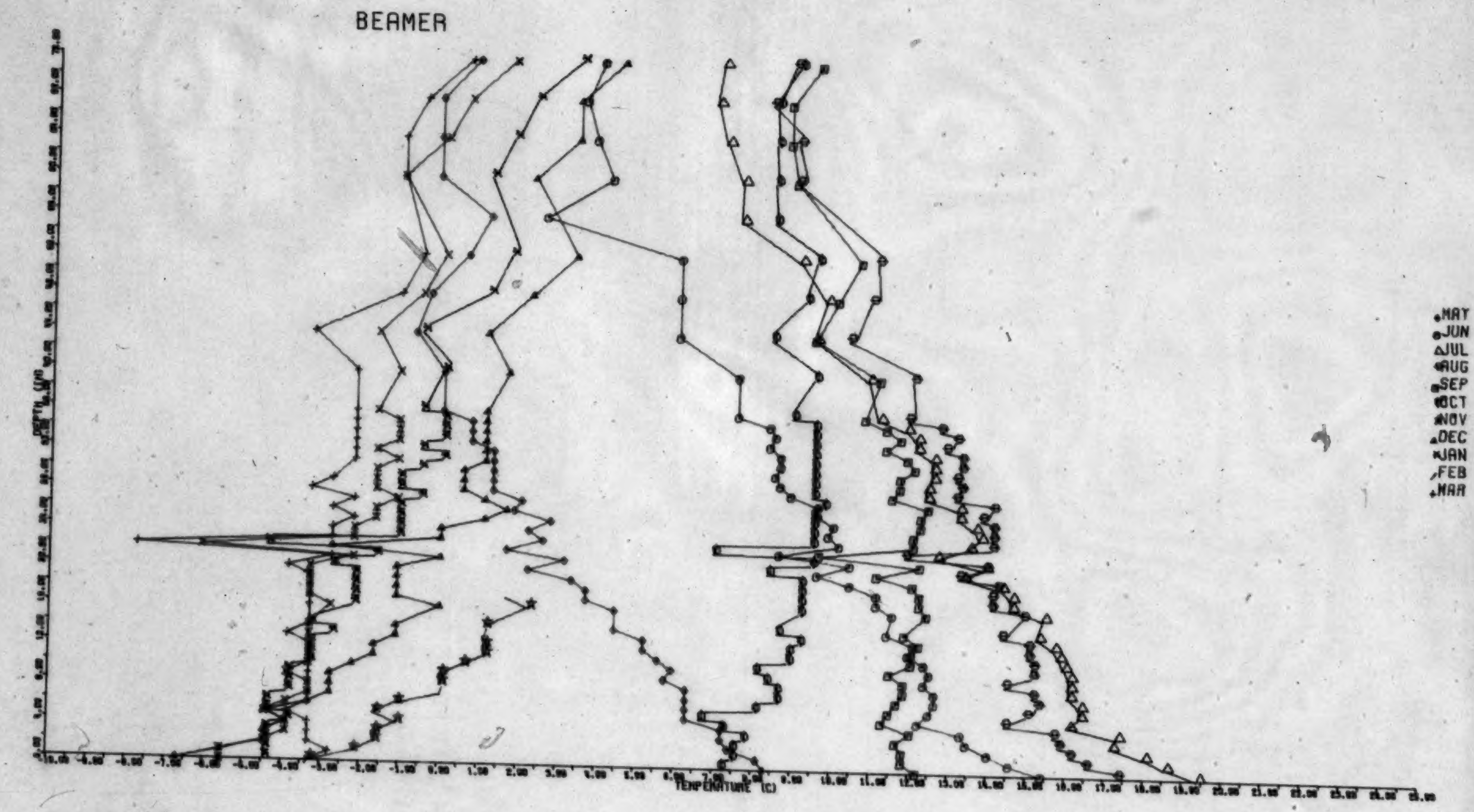

Figure 6: Average monthly soil temperatures in ^{o}C at the Beamer site from May 1979 to March 1980

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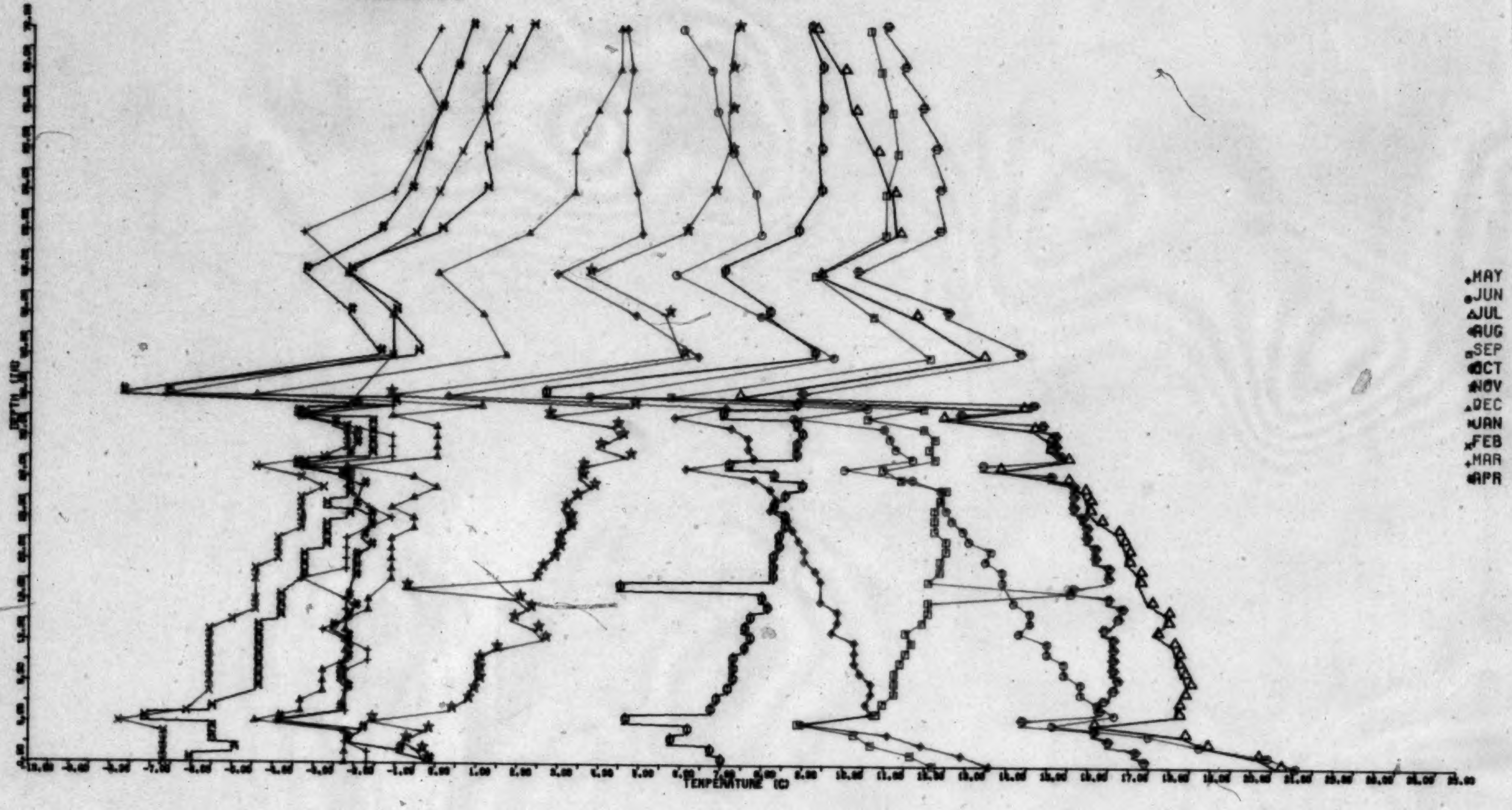


Figure 7: Average menthly soil temperatures in ^{0}C at the Paulencu site from May 1978 to April 1979.

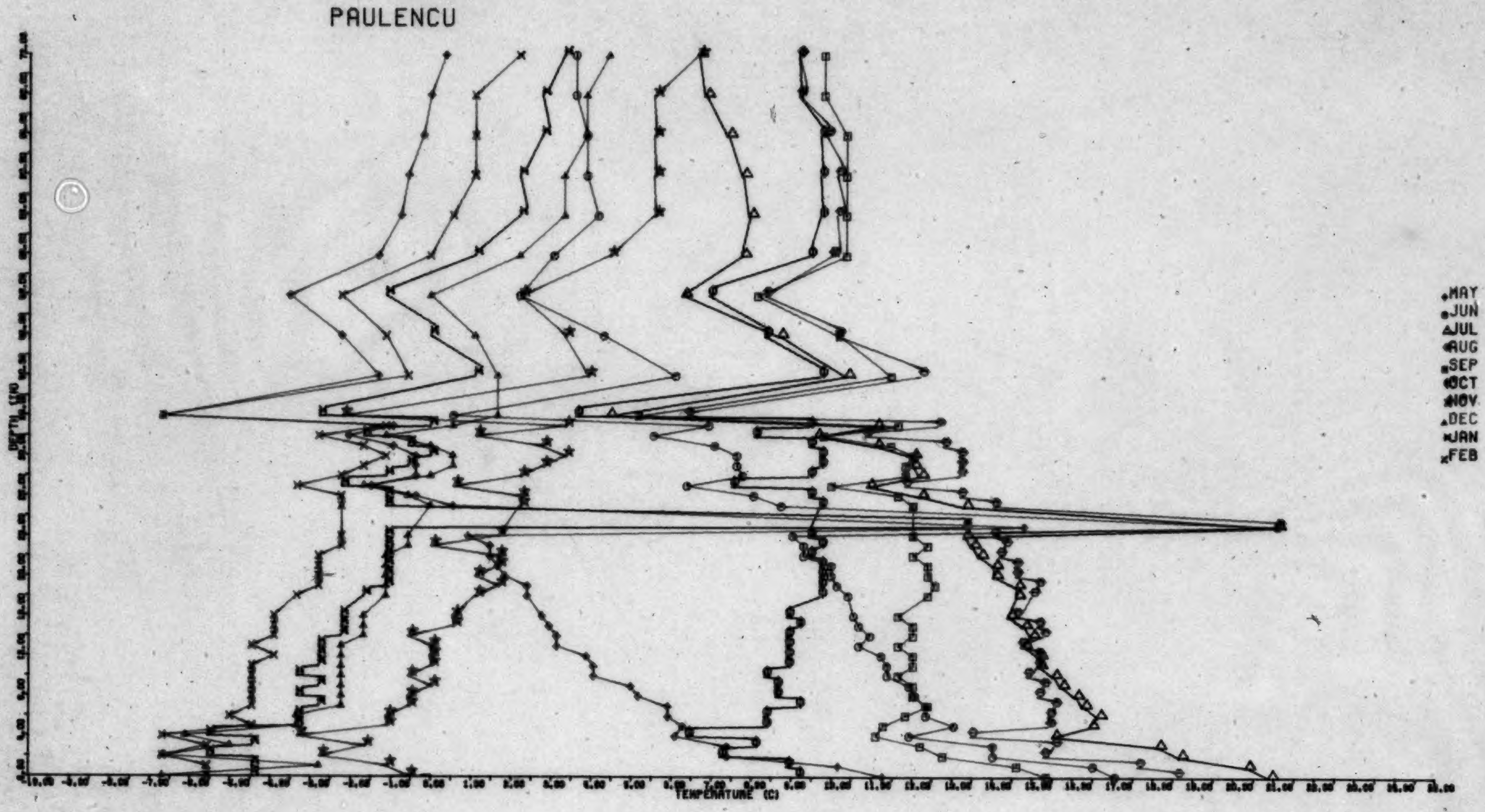
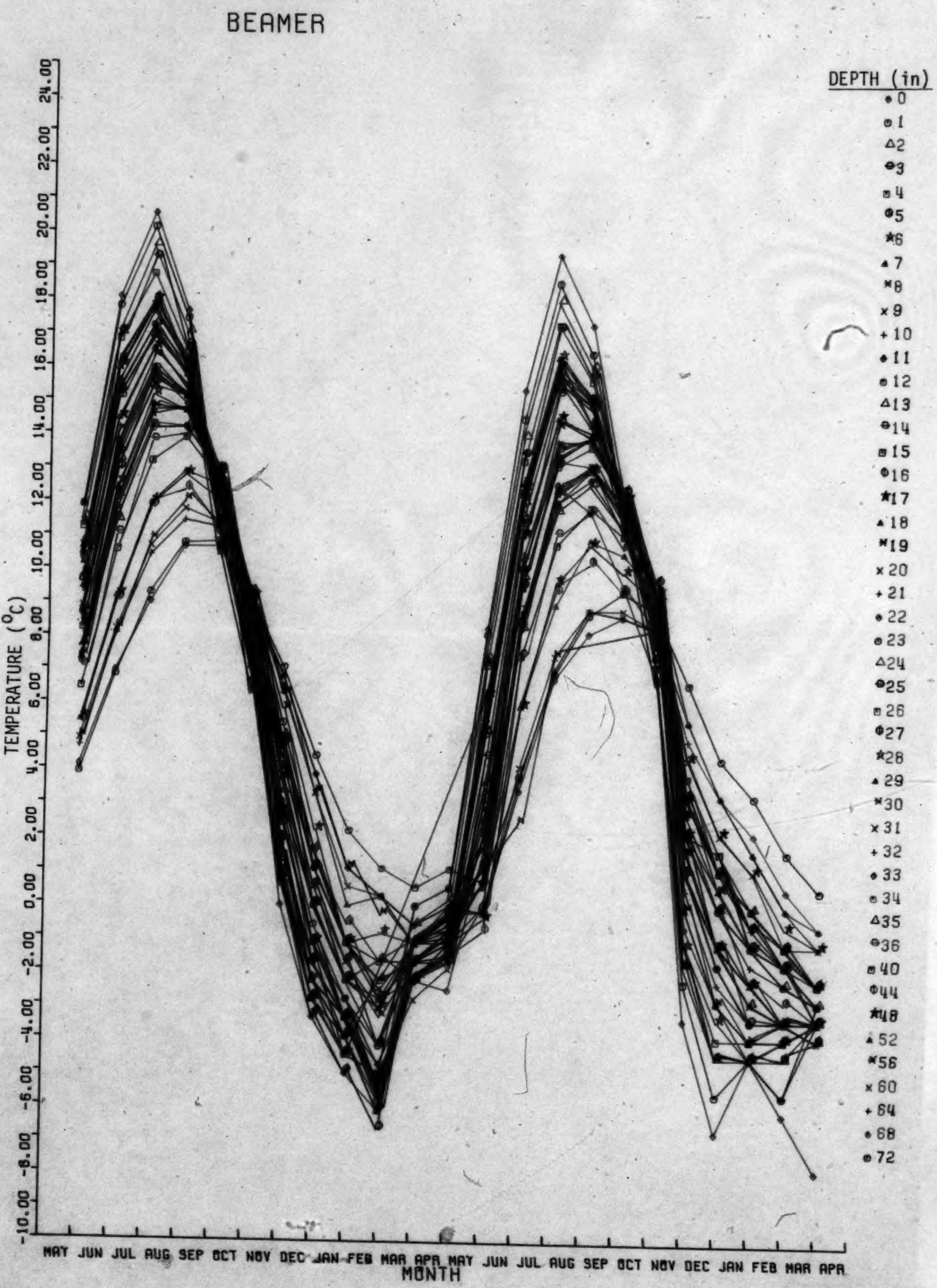


Figure 8: Average monthly soil temperatures in ^{o}C at the Paulencu site from May 1979 to February 1980

Figure 9: Average monthly soil temperatures in °C at the Beamer site from May 1978 to March 1980.



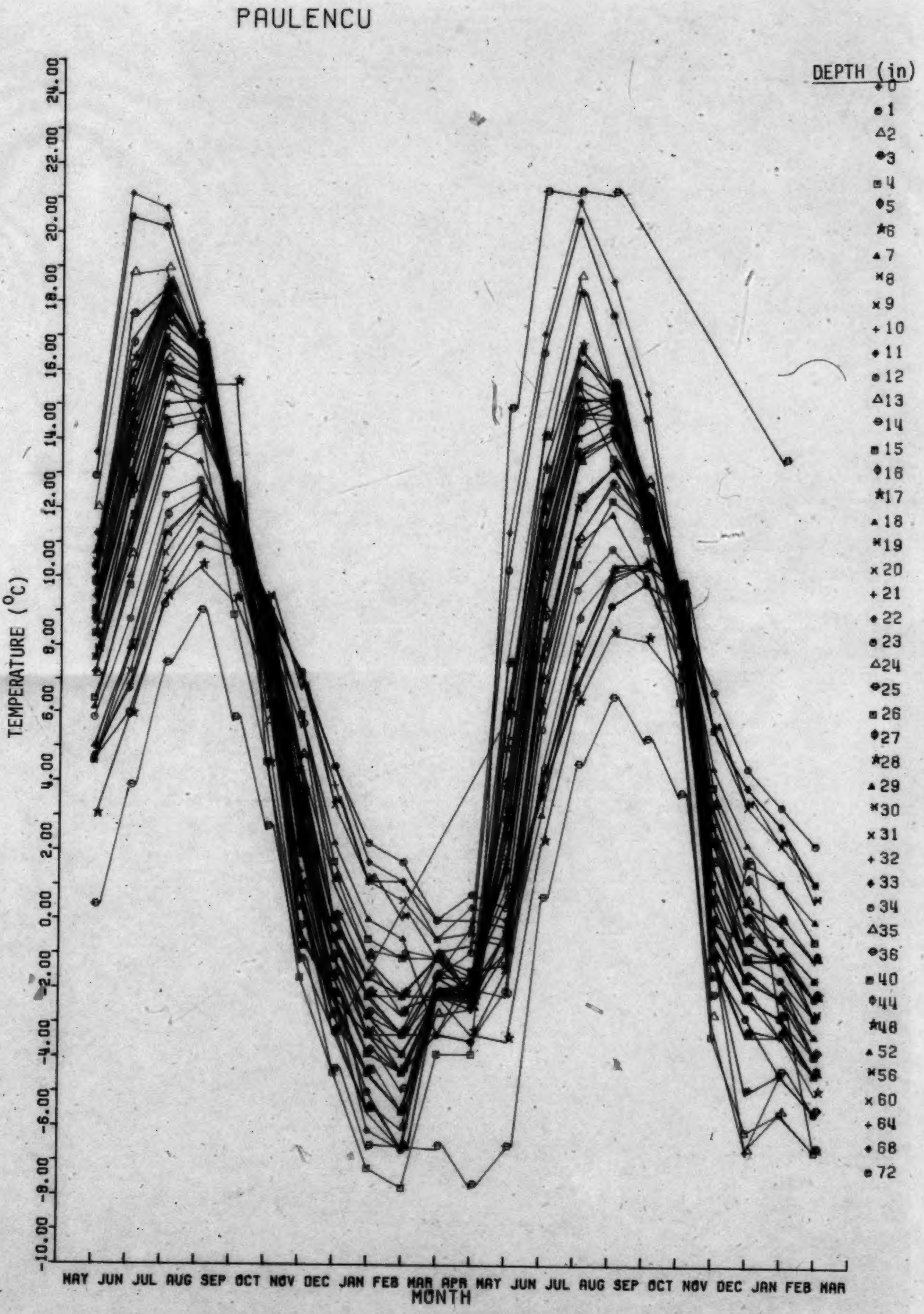


Figure 10: Average monthly soil temperatures in °C at the Paulencu site from May 1978 to February 1980.